Use of Pumice in Mortar and Rendering for Lightweight Building Blocks

Osman İlter

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Prof. Dr. Elvan Yılmaz
Director (a)

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Asst. Prof. Dr. Mürüde Çelikağ
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Prof. Dr. Tahir Çelik
Co-Supervisor

Assoc. Prof. Dr. Özgür Eren
Supervisor

Examining Committee

1. Prof. Dr. Tahir Çelik
2. Assoc.Prof. Dr. Özgür Eren
3. Assoc. Prof. Dr. Zalihe Nalbantoğlu
4. Asst. Prof. Dr. Mehmet M. Kunt
5. Asst. Prof. Dr. Mustafa Ergil

ABSTRACT

The usage of lightweight aggregates in concrete or mortar is increasing remarkably due to energy and safety reasons. The important factor for energy saving (heat insulation) in buildings is the used construction materials and their thermal properties. Pumice is an abundantly consumed, cheap and important industrial raw material for the lightweight aggregate that essentially used for making building blocks. The usage of porous lightweight aggregate is becoming common world wide as a heat insulation material and important part of the world pumice reserves is in Turkey. Nowadays, usage of building elements produced from this material is becoming highly widespread.

In North Cyprus, use of pumice was introduced with Pumice Blocks. It is widely accepted by the civil engineers and architects that walls made of pumice block could insulate both heat and sound and reduce the dead load of building compared to traditional wall elements like clay brick. It is known that these blocks are bonded together with normal mortar. Also, plaster applied on these block is made with sand-cement mixtures. In this study two parameters namely; mortar and plaster were developed by using pumice as aggregates instead of limestone crushed aggregate (traditional aggregate). The proportioning of the materials were changed in order to get the best mixture in terms of physical and mechanical properties of the products.

Properties that were measured for mortars include, consistency of fresh mortar, time of settings, fresh unit weight, hardened unit weight, water absorption, coefficent of capillary water absorption, drying shrinkage, flexural strength, compressive strength and ultrasonic pulse velocity. Also coefficent of thermal conductivity of different wall systems made with pumice and limestone mortars were determined. This study showed that the properties of pumice mortars indicating lower values compared to limestone mortars based on workability duration, time of settings, fresh unit weight, hardened unit weight and ultrasonic pulse velocity. Properties of pumice mortars which indicate higher values compared to limestone mortars are the water absorption, the coefficent of capillary water absorption, the drying shrinkage, the flexural strength and the compressive strength. Besides, this research showed that, wall systems made with pumice mortar and plaster supplied significant benefit to pumice block heat insulation properties compared to wall system made with limestone mortar and plaster. On the other hand, the coeffient of thermal conductivity of pumice block wall systems were compared with traditional wall system made with clay brick are showed that, pumice block wall systems had lower coefficent of thermal conductivity compared to clay brick wall systems implying that pumice blocks wall systems provided better heat insulation performance.

Keywords: lightweight plaster, Pumice, Thermal insulation, Limestone aggregate, Thermal conductivity.

ÖZ

Enerji ve güvenlik sebeplerinden dolayı hafif agregaların beton ve harç yapımında kullanılması dikkate değer şekilde artmaktadır. Yapılarda ısı yalıtımını sağlayan başlıca faktörler, kullanılan yapı malzemesi ve malzemenin termal özellikleridir. Pomza dünya inşaat sektöründe ısı ve ses izolasyonu sağlamak için bol miktarda tüketilen ucuz ve önemli bir hammaddedir ve esasen duvar blok elemanı yapımında kullanılan en popüler hafif agregadır. İnşaat sektöründeki uygulamalarda gözenekli hafif agregaların ısı yalıtımı malzemesi olarak kullanılması giderek yaygınlaşmaktadır. Dünya pomza rezervlerinin önemli bir bölümü Türkiye sınırları dahilindedir. Günümüzde ülkemiz inşaat sektöründe de bu malzemeden üretilen yapı elemanlarının kullanımı hızla yaygınlaşmaktadır.

Kuzey Kıbrıs'ta, pomza kullanımı Bims-Blok ile başlamıştır. Bims-Blok elemanlarının diğer geleneksel kullanılan kil tuğla elemanlara nazaran yüksek ısı ve ses izolasyonu ve hafifliği ile binanın zati yükünü azaltmaktadır. Bu nedenle sebebi ile ülkemizdeki Mimarlar ve İnşaat Mühendisleri tarafından kullanımı tercih edilmektedir. Duvar elemanları normal kumla yapılan harçla örülmektedir. Ayrıca duvar elemanlarına uygulanan sıvada normal kumlu karışımla yapılmaktadır. Bu çalışmada bu iki parametre (harç ve sıva) kireçtaşı agregası (normal kum) yerine pomza agregasını kullanılması ile geliştirilmiştir. Oluşturulması hedeflenen harç ve sıvanın en iyi fiziksel ve mekaniksel özelliklere sahip olması için kullanılacak malzeme miktarlarının oranları saptanmıştır.

Harçlar için yapılan deneysel çalışmalarda ölçülen özellikler sırası ile, taze harcın kıvamı, priz süreleri, taze birim hacim ağırlık, kuru birim hacim ağırlık, su emme kapasitesi, kılcal yolla su emme katsayısı, kuruma rötresi, eğilme mukavemeti, basınç mukavemeti ve ultrasonik akım hızlarıdır. Ayrıca pomzalı ve kireçtaşı (normal kum) agregalı harç ve sıvaların uygulanması ile oluşturulan farklı duvar sistemlerinin ısı iletkenlik katsayıları çalışılmıştır. Elde edilen sonuçlara göre, pomzalı harcın normal kumlu harca nazaran değerinin düşük olduğu özellikler, işelenebilirlik süresi, prizlenme süresi, taze birim hacim ağırlık, kuru birim hacim ağırlık ve ultrasonik akım geçiş hızıdır. Pomzalı harcın normal kumlu harca nazaran değerinin yüksek olduğu özellikler ise, su emme kapasitesi, kılcal yolla su emme katsayısı, kuruma rötresi, eğilme mukavemeti ile basınç mukavemetidir. Ayrıca pomza harçlı ve sıvalı duvar sistemlerinin bimsblok ısı yalıtım özelliklerine önemli oranda katkı sağladığı görülmüştür. Öte yandan bims blok duvar sistemleri ile geleneksel duvar malzemesi olan kil tuğla ile yapılan duvar sisteminin ısı iletkenlik katsayısı karşılaştırılmıştır. Elde edilen sonuca göre bims blok ile yapılan duvar sistemlerinin kil tuğla ile yapılan duvar sistemlerine nazaran ısı iletkenlik katsayısının daha düşük olduğu görülmüştür ki bu sonuç ile bims blok duvar sistemlerinin kil tuğla ile yapılan duvar sistemelerine oranla daha iyi ısı yalıtım özelliği gösterdiği görülmüştür.

Anahtar Kelimeler: Hafif sıva, pomza agregası, ısı izolasyonu, kireçtaşı agregası, ısı iletkenlik katsayısı.

To My Family

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a	Acceleration
A_S	Surface Area of Specimen Sinked into Water
a_1	Longitudinal Exterior Wall Thickness
a_2	Crosswise Exterior Wall Thickness
ASTM	American Society for Testing Materials
b	Thickness of Pumice Block
b	Cross Section of Square Edge
BIA	Brick Industry Association
BS	British Standard
c	Interior Wall Thickness
Cws	Coefficient of Capillary Water Absorption
d_1	Breast Mortar Length
e	Breast Mortar Thickness
F	Horizontal Force
h	Height of Pumice Block
J	Joule
K	Kelvin
L	Length of Pumice Block
L	Length between Two Supports
L	Path Length
m	Mass of a Object
m	Meter

MPa	MegaPascal
$m_{so,s}$	Wet Mass
$m_{dry,s}$	Dry Mass
N	Newton
P	Applied Force (Failure Force)
S_R	Flexural Strength
SSD	Saturated Surface Dry
T	Transmit Time
TS	Turkish Standard
t_{so}	Contact Time of Water
W	Watt
V	Pulse Velocity
λ	Coefficient of Thermal Conductivity

Chapter 1

INTRODUCTION

1.1 General

Nowadays, earthquake resistance, cost, quality and energy conservation are the most important criteria in building design.

In recent years, the observed acceleration in construction sector causes to use superior technical performance building materials in construction. The importance of usage of lightweight aggregate in concrete industry is better understood by the results of earthquake events. Many concrete producers have performed scientific studies to use light and natural materials in concrete. Pumice, volcanic slag, diatomic and perlite formations can be counted as lightweight natural aggregates. However these natural aggregates are required to provide essential features in terms of engineering and industrial sense. In recent years, due to technical advantages the lightweight wall elements have been produced with pumice aggregates is considered as a filler element in wall construction. As it is known, the lightweight materials used in residential buildings are an important factor that causes to reduce in dead load of the structure. In terms of structure of a building, reduction in dead load causes more resistance against the earthquake forces. Therefore usage of lightweight aggregates has increased its importance in construction sector [8].

A great amount of consumed energy is used for heating and cooling of the buildings actively and this situation causes to increased heating and cooling costs (energy consumption). External walls which are losing heat are the most important components of a building. High thermal resistance of external walls brings a much better comfort to a building [23]. Pumice is an abundantly consumed, cheap and important industrial raw material for the lightweight aggregate that essentially used for making building blocks. The usage of porous lightweight aggregate is becoming common world wide as a heat insulation material. Using pumice in construction makes it possible to hold interior temperatures of closed volumes at desired level, provide energy savings in heating-cooling applications against exterior climate conditions. Pumice block is a wall construction material which is prepared with pumice aggregate, cement and water. Adequate thermal resistance is obtained by external walls made of these kind of blocks and possible problems related with heat and moisture are solved and the internal surface heat is kept at a reasonable level. According to the changing internal and external conditions, external wall made of pumice block, balances many components forming thermal comfort and achieves the comfort in internal place, in terms of energy, economy and health [23].

In N. Cyprus energy conservation is one of the most important issue that always keep up its importance. Especially from cost of fuel and electricity point of view, thermal insulation in buildings provide economical benefits. Energy is mainly consumed for the purpose of heating and cooling in the residential buildings. About 45 % of the total amount of energy is consumed for heating and cooling process in ordinary residential buildings [24].

The thermal insulation and self weight of lightweight concrete improved its application in construction sector of N.Cyprus. Use of natural and porous aggregates has begun increasing popularities in terms of lightweightness as well as heat and sound insulation properties.

In N.Cyprus, use of pumice was introduced with pumice block. Pumie blocks are manufactured in order to use as infill wall construction material with the purpose of achieve higher heat insulation performance in buildings. This materials are become very popular in construction sector of N.Cyprus due to provide significant benefits in terms of lightweightness and heat insulation properties. The important factor for energy saving (heat insulation) in building is the used construction materials and their thermal properties. Coefficient of thermal conductivity is the most important property of a material that describe the heat insulation performance of a material. Lower coefficient of thermal conductivity indicates higher thermal insulation performance of a material. Therefore in this research, thermal conductivity coefficients of wall systems formed by pumice block together with applied mortar and plaster was investigated and comparison was done among clay brick wall systems which is accepted as a traditional wall system in N.Cyprus in order to exposed differences of thermal insulation performances of pumice block and clay brick.

In N.Cyprus, it is known that mortar / plaster applied on masonry units are made with limestone –cement mixtures. In this research, basicly two types of aggregates were used which were pumice as lightweight aggregate and limestone as traditional aggregate in order to produce mortar and plaster and applied on wall systems. Mortar and plaster were produced by using pumice as lightweight aggregate instead of limestone crushed aggregate in order to further improve the heat insulation performences and to reduce the self weight (dead load) of the wall systems. Therefore in this research the effects of pumice aggregate in mortar and plaster were examined and comparasion was done with mortar / plaster (traditional) made of limestone aggregate based on physical, mechanical and thermal conductivity coefficent.

Coefficient of thermal conductivity of wall systems were determined by HOT-BOX device (TS EN ISO 8990). To measure the thermal conductivity, different wall systems were formed by use of different type of masonry units which were pumice block and clay brick and applied different type of mortar / plaster which were pumice and limestone mortar / plaster. Results obtained in this research throughout experimental studies were analyzed and compared among themselves.

Experimental research findings also showed that clay brick wall system has about 1.5 times higher thermal conductivity coefficent compared to pumice block wall systems. Therefore experimental results showed that pumice-block wall systems provides better heat insulation performance compared to wall system made with traditional clay brick. Furthermore, use of pumice mortar / plaster instead of limestone mortar / plaster (traditional) in pumice-block wall systems provides about 16 % extra contribution in thermal insulation performance of the wall.

1.2 Aims and Objectives of the Research

Experiments were undertaken to determine the properties of traditional and lightweight pumice mortars. The results of experiments were analyzed and compared in terms of physical and mechanical properties as well as coefficient of thermal conductivity of different wall systems. In this research, thermal conductivity coefficients of wall systems formed by pumice block together with applied mortar and plaster was investigated and comparison was done among clay brick wall systems.

The objectives of this thesis are as follows:

1. To survey the literature on related study (lightweight concrete, pumice aggregate, pumice block, mortar and plaster).
2. To determine the physical properties of aggregates (limestone and pumice) used in this investigation.
3. To determine mix proportions (mix design) of joint mortar and plasters made of limestone and pumice aggregate.
4. To study the differences in physical and mechanical properties between traditional mortar/plaster made with limestone aggregate and lightweight pumice aggregate.
5. To determine the thermal conductivity coefficient of plaster applied on seven different wall systems.
6. To analyze and compare results obtained throughout experimental study.

1.3 Works Done

In order to achieve the objectives explained in section 1.2, the followings were done:

1. A comprehensive literature survey was undertaken on related study (lightweight concrete, pumice aggregate, pumice block, mortar and plaster).

2. Physical properties such as bulk density, specific gravity, percentage of absorption, particle size distribution of limestone and pumice aggregate were obtained and compared among themselves.
3. Mix proportions (mix design) of traditional mortar / plaster and lightweight pumice mortar / plaster are determined. First coat and second coat of plaster as well as joint mortars are produced by using limestone and pumice aggregate by following the revelant standards and specifications used in general construction Works in N.Cyprus. In recent years ready mixed plasters are applied as a third coat plaster in wall plastering. Therefore, ready mixed plaster was applied as a third coat plastering (finishing) on wall specimen recently by many construction sectors.
4. Experimental studies based on determination of fresh mix, hardened mix (physical) and mechanical properties of traditional mortar / plaster and lightweight pumice mortar/plaster were performed.
5. Coefficient of thermal conductivity of different wall systems in terms of different mortar / plaster as well as block types were determined and compared among themselves and with traditional wall made of clay bricks (size 100x200x300 mm).
6. Finally all results obtained from experimental studies were anaylzed and compared among themself. Comparasion of traditional mortar/plaster and lightweight pumice mortar/plaster based on physical and mechanical properties and comparasion of different wall systems based on thermal conductivity coefficient were done in this investigation.

1.4 Achievements

The achievements in this study are as follows:

1. A detailed literature survey from various previous studies and resources were performed in order to obtain detailed information on related subjects basicly lightweight concrete, pumice aggregate, pumice block, mortar, plaster and thermal properties of masonry systems.
2. Experimental research findings showed that bulk density of pumice aggregates used in this research are 2.5 times lower compared to limestone aggregates. Specific gravities of pumice aggregates used in this research are around 2 times lower than the specific gravities of limestone aggregates. The percentage of water absorption of pumice aggregate used in this research is around 14 times much higher compared with limestone aggregate. The particle size distribution of limestone aggregates are almost same compared with pumice aggregates used in this investigation. The maximum size of aggregate was 2 mm used in production of mortar and plaster both for pumice and limestone mortar.
3. Mix proportions (mix design) of traditional mortar / plaster and lightweight pumice mortar / plaster are determined according to technical specification for construction work prepared by 'Union of the Chambers of Cyprus Turkish Engineers and Architects (KTMMOB). In this investigation mix proportions by volume were converted to proportions by weight in order to establish the amount of materials used in the mixes. Consistency of both pumice and traditional mortars except first coat were tried to kept in the same range. The consistency of first coat both pumice and traditional is more fluid compared with second coat and joint mortars.
4. Fresh mix properties (consistency of fresh mortar, time of setting, and fresh unit weight of mortars) were performed seperately for traditional and pumice

mortars in terms of first coat, second coat and joint mortars. Mechanical properties (compressive strength, flexural strength, pulse velocity) were determined seperately for traditional and pumice mortars in terms of first coat, second coat and joint mortars. Hardened mix properties (capillary water absorption, water absorption, hardened unit weight and drying shrinkage) of mortars were determined in terms of first coat, second coat and joint mortars.

5. Experimental research findings showed that, coefficient of thermal conductivity of pumice block wall systems made with limestone mortar / plaster has about 1.2 times higher compared to pumice block wall systems made with pumice mortar / plaster. Moreover coefficient of thermal conductivity of clay brick wall system has about 1.5 times higher compared to pumice block wall system.
6. The experimental research findings showed that, the properties of pumice mortars which indicate lower value compared to limestone mortars, are workability duration, time of settings, fresh unit weight, hardened unit weight, and ultrasonic pulse velocity. Properties of pumice mortars which indicate higher value compared to limestone mortars are, percentage of water absorption, coefficient of capillary water absorption, percentage of drying shrinkage, flexural strength and compressive strength. Experimental findings also showed that wall systems made with pumice mortar / plaster have a lower coefficient of thermal conductivity compared to wall systems made with limestone mortar / plaster.

1.5 Guide to Thesis

Chapter 2 includes definition of lightweight concrete, historical background of lightweight concrete, types of lightweight aggregate, application area of lightweight concrete and classification of lightweight concrete are explained. Lightweight pumice aggregate, deposits and reservoirs of pumice, usage area of pumice and usage area of pumice in construction sector are explained in detail. Description of pumice block, pumice block production process, products of pumice block and benefits of using pumice blocks in buildings are explained as well. Definition of mortar, properties of mortar, kinds of mortar, selection of right mortar type and related items that have an effect on properties of mortar are explained in detail. Definition of plastering, requirements of good plastering, methods of plastering and types of plastering are also detailed. Thermal properties of masonry system, thermal conductivity of concrete, thermal conductivity of concrete used in concrete masonry unit, thermal mass of concrete masonry systems and factors affecting the thermal mass effects are also detailed in chapter 2.

Chapter 3 deals with experimental part of this research where the properties of materials such as aggregates and pumice block and mix proportioning of mortar and plaster are explained in detail.

Chapter 4 contains the results, analyses of results and discussion of results throughout experimental studies.

Chapter 5 deals with conclusions and recommendation of this research.

Chapter 2

LIGHTWEIGHT CONCRETE

2.1 Introduction

In this chapter, a comprehensive literature survey from various resorces were undertaken on about lightweight concrete, pumice aggregate, pumice block, mortar, plaster and thermal properties of masonry systems.

2.1.1 Definition of Lightweight Concrete

Both “Lightweight Concrete” and “Lightweight Aggregate” are general terms which include a wide variety of products and are frequently subject to varying definitions. There are several methods to produce lightweight concrete. These are:

(a) By using porous lightweight aggregate of low apparent specific gravity, i.e. lower than 2.6. This type of concrete is known as lightweight aggregate concrete.

(b) By introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from extremely fine voids produced by air entrainment. This type of concrete is variously known as aerated, cellular, foamed or gas concrete.

(c) By omitting the fine aggregate from the mix so that a large number of interstitial voids is present; normal weight coarse aggregate is generally used. This concrete is known as no-fines concrete [1].

In essence, the decrease in density of the concrete in each method is obtained by the presence of voids, either in the aggregate or in the mortar or in the interstices between the coarse aggregate particles. It is clear that the presence of these voids reduces the strength of lightweight concrete compared with ordinary, normal weight concrete, but in many applications high strength is not essential and in others there are compensations.

Because it contains air-filled voids, lightweight concrete provides good thermal insulation and has a satisfactory durability but is not highly resistant to abrasion. In general, lightweight concrete is more expensive than ordinary concrete, and mixing, handling and placing require more care and attention than ordinary concrete. However, for many purposes the advantages of lightweight concrete outweight its disadvantages, and there is a continuing world-wide trend towards more lightweight concrete in applications such as prestressed concrete, high-rise buildings and even shell roofs [1].

2.1.2 Historical Background of Lightweight Aggregate Concrete

The use of lightweight aggregate concrete (LWAC) can be traced to as early as 3000 BC, when the famous towns of Mohenjo-Daro and Harappa were built during the Indus Valley civilization. In Europe, earlier use of LWAC occured about two thousand years ago when the Romans built the Pantheon, the aqueducts, and the Collosseum in Rome.

Earlier lightweight aggregate (LWA) were of natural origin, mostly volcanic; (pumice, scoria, tuff, etc). These have been used both as fine and coarse aggregate. They function as active pozzolanic material when used as fine aggregate. They interact with calcium hydroxide generated from the binder during hydration and produce calcium silicate hydrate which strengthens the structure and modifies the pore structure, enchancing the durability properties [2].

Pumice mine has been used first by Greek and later by Romans long before Cristianism. It has been used in wall construction, water channels and many other monumental structures in Roma. In U.S.A pumice mine has been used since 1851 in construction. Additionally pumice has been used from 1908 to 1918 in aqueduct construction in Los Angeles. It has been started to be used as lightweight insulating building material since 1935 in U.S.A and after that showed steady increase in this sector. In U.S.A despite early usage of pumice in the domestic construction industry, has fallen behind compared to the other countries. Before Wold War 2 Germany has been possesed a strong trade in lightweight building materials unit in the world [3].

The Greeks and the Romans used pumice in building construction. Some of these magnificent ancient structures still exist, like St. Sofia Cathedral or Hagia Sofia, in Istanbul, Turkey, built by two engineers, Isidore of Milctus and Anthemius of Tralles, commissioned by the Emperor Justinian in the 4 th century A.D., the Roman temple, Pantheon which was erected in the years A.D. 118 to 128; the prestigious adueduct, Pont du Gard, built A.D. 70 and 82. In addition to building construction, the Romans used natural lightweight aggregates and hollow vases for their " Opus Caementitium" in order to reduce the weight. This was also used in the construction of the Pyramids during the Mayan period in Mexico [2].

In U.K, clinker aggregate concrete was used in the construction of the British Museum in the early part of the 20 th century. In 1918, Stephen J. Hayde patended the lightweight aggregate "Haydite" the first made the expansion of shale, which came into the production in the US. Synthetic aggregates of this type have been universally accepted and used satisfactory for reinforced or prestressed concrete.

The first building frame of reinforced LWAC in Great Britain was a three story Office block at Bentford, near London, built in 1958. Since then, many structures have been built of precast, in-situ prestressed, or reinforced lightweight aggregate concrete.

Other early application are the ship built with the LWAC at the end of World War 1, 1917. One of the famous ship was named as Selma. After so many years of service in harsh climate, it is still in satisfactory condition. This imples of the durability of the Lightweight Aggregate Concrete. In addition to the materials, the techniques adopted by the ship builders to construct the ship is equally important. It was so well constructed that some of the factors have become specifications for ship making [2].

Pumice is still used today as an aggregate for making masonry unit and lightweigh structural concrete in certain countries such as Turkey, Germany, Italy, Iceland and Japan. In some places, like Malaysia, palm oil shells are used for making lightweight aggregate concrete [2].

2.1.3 Types of Lightweight Aggregate

The first distinction can be made between aggregates occurring in nature and those manufactured. The main natural lightweight aggregates are pumice, scoria, diatomite, volcanic cinders, and tuff; except for diatomite, all of these are of volcanic origin. Pumice is more widely employed than any of the others but, because they are found only in some areas [1].

Pumice is a light-coloured, froth-like volcanic glass with varying a bulk density of 500 to 900 kg/m^3. Those variety of pumice which are not too weak structurally make a satisfactory concrete with a density of 700 to 1400 kg/m^3 and with good insulating characteristics, but having high absorption and high shrinkage [1].

Scoria, which is a vesicular glassy rock, rather like industrial cinders, gives a concrete of similar properties [1].

Artificial aggregates are known by a variety of trade names, but are best classified on the basis of the raw material used and the method of manufacture [1].

First type the aggregates produced by the application of heat in order to expand clay, shale, slate, diatomaceous shale, perlite, obsidian and vermiculite. Second type is obtained by special cooling processes through which an expansion of blast-furnace slag is obtained [1].

Expanded clay, shale, and slate are obtained by heating raw materials in a rotary kiln to incipient fusion (temperature of 1000 to 1200 °C) when expansion of the material takes place due to the generation of gases which become entrapped in a viscous pyrpoplastic mass. This porous structure is retained on cooling so that the apparent specific gravity of the expanded material is lower than before heating. Expanded shale and clay aggregates made by sinter strand process have a density of 650 to 900 kg/m^3, and 300 to 650 kg/m^3 when made in a rotary kiln. They produce concrete with a density usually within the range of 1400 to 1800 kg/m^3, althought values as low as 800 kg/m^3 have been obtained as well. Concrete made with expanded shale or clay aggregates generally has a higher strength than when any other lightweight aggregate is used [1].

Perlite is a glassy volcanic rock found in America, Ulster, Italy and elsewhere. When heated rapidly to the point of incipient fusion (900 to 1100°C), it expands owing to the evolution of stream and forms a cellular material with a bulk density as low as 30 to 240 kg/m^3. Concrete made with perlite has a very low strength, a very high shrinkage and is used primarily for insulation purposes. An advantage of such concrete is that it is fast drying and can be finishing operation [1].

Vermiculite is a material with a plate structures, and is found in America and Africa. When heated to a temperature of 650 to 1000°C, vermiculite expands to several, or even as many as 30 times to its original volume by exfoliation of its thin plates. As a result, the bulk density of exfoliated vermiculite is only 60 to 130 kg/m^3 and concrete made with it is of very low strength and exhibits high shrinkage but having an excellent heat insulating [1].

Expanded blast-furnace slag is produced in two ways. In one, a limited amount of water in the form of a spray comes into contact with the molten salg as it is being discharged from the furnace. Stream is generated and it bloats the stil plastic slag, so that the slag hardens in a porous form, rather similar to pumice. This is the water-jet process. In the machine process, the molten slag is rapidly agitated with a controlled amount of water. Expanded or foamed slag has been used for many years and is produced with a bulk density varying between 300 and 1100 kg/m^3, depending on the details of the cooling process and, to a certain degree, on the particle size and grading [1].

Fly ash is processed for the use of lightweight aggregate by mixing with sufficient moisture to permit it to be either pelletized or extruded to form spherical or cylindrical shapes that can be sintered. Carbon present in the fly ash forms all or a large part of the fuel required after ignition. Fine aggregate sizes can be produced by crushing after sintering and cooling [4].

Clinker aggregates, known in the US as cinders, is made from well-burnt residue of industrial high-temperature furnaces, fused or sintered into lumps. It is important that the clinker be free from harmful varieties of unburnt coal, which may undergo expansion in the concrete, thus causing unsoundness. BS 3797:1990 lays down the limits of loss on ignition and of soluble sulphate content in clinker aggregate to be used in plain concrete for general purposes and in in situ interior concrete not normally exposed to damp condition. Standards are not recommending the use of clinker aggregate in reinforced concrete or in concrete required due to high durability [1].

When cinders are used as aggregates, concrete with a density of about 1100 to 1400 kg/m^3 is obtained, but often natural sand is used in order to improve the workability of the mix where the density of the resulting concrete is in the range of 1750 to 1850 kg/m^3 [1]. It should be noted that, in contrast to normal weight aggregate, the finer particles of lightweight aggregate generally have a higher apparent specific gravity than the coarser ones. This is caused by the crushing process where fracture occurs through the larger pores so that the smaller the particle the smaller the pores in it [1].

2.1.4 Properties of Lightweight Aggregate Concrete

The various types of lightweight aggregate available allow the density of concrete to range from a little over 300 up to 1850 kg/m^3, with a corresponding compressive strength ranging of 0.3 and 40 MPa and sometimes even higher. Compressive strengths up to 60 MPa can be obtained with very high cement content (560 kg/m^3) [1].

The suitability of a lightweight concrete is governed by the desired properties: density, cost, strength, and thermal conductivity. The low thermal conductivity of lightweight aggregate concrete is clearly advantageous for applications requiring very good insulation, but the same property causes a higher temperature rise under mass-curing conditions, which is revelant to the possibility of early-age thermal cracking [1].

Other properties which have to be considered are workability, absorption, drying shrinkage, and moisture movement. For equal workability (easy of compaction), lightweight aggregate concrete registers a lower slump and a lower compacting factor than normal weight concrete because the work done by gravity is smaller in the case of the lighter material. A consequential danger is that, if a higher workability is used, there is a greater tendency to segregation [1].

The porous nature of lightweight aggregates means that they have high and rapid water absorption. Thus, if the aggregate is dry at the time of mixing, it will rapidly absorp water and the workability will quickly decrease [1].
Lightweight aggregate mixes tend to be harsh, but hashness can be reduced by air entrainment: water requirement is reduced and so is the tendency to bleeding and segregation. The usual total air contents by volume are: 4 to 8 per cent for 20 mm maximum size of aggregate, and 5 to 9 per cent for 10 mm maximum size of aggregate. Air contents in excess of these values lower the compressive strength by about 1 MPa for each additional percentage point of air [1].

The use of lightweight fines, as well as of lightweight coarse aggregate, aggrevates the problem of low workability. It may, therefore, be preferable to use normal weight fines with lightweight coarse aggregate. Such concrete is referred to as semi-lightweight (or sand-lightweight) concrete, and of course, its density and thermal conductivity are higher than when all-lightweight aggregate is used. Typically, for the same workability, semi-lightweight concrete will require 12 to 14 per cent less mixing water than lightweight aggregate concrete. The modulus of elasticity of semi-lightweight concrete is higher and its shrinkage is lower than when all-lightweight aggregate is used [1].

Some other properties of lightweight aggregate concretes as compared with normal weight concrete may be of interest:

(a) For the same strength, the modulus of elasticity is lower by 25 to 50 per cent; hence, deflections are greater.

(b) Resistance to freezing and thawing is greater because of the greater porosity of the lightweight aggregate, provided the aggregate is not saturated before mixing.

(c) Fire resistance is greater because lightweight aggregate have a lesser tendency to spall; the concrete also suffers a lower loss of strenght with a rise in temperature.

(d) Lightweight concrete is easier to cut or to have fitments attached.

(e) For the same compressive strenght, the shear strength is lower by 15 to 25 per cent and the bond strength is lower by 20 to 50 per cent.

(f) The tensile strain capacity is about 50 per cent greater than in normal weight concrete. Hence, the ability to withstand restraint to movement, e.g. due to internal temperatute gradients, is greater for lightweight concrete.

(g) For the same strength, creep of lightweight aggregate concrete is about the same as that of normal weight concrete [1].

(h) Thermal insulation value of lightweight concrete is about three to six times that of bricks and about ten times that of concrete. A 200 mm thick wall of aerated concrete of density 800 kg/m^3 has the same degree of insulation as a 400 mm thick brick wall of density 1600kg/m^3 [5].

(i) Sound insulation value of lightweight concrete is higher compared with dense concrete [5].

(j) Lightweight products can be easily sawn, cut, drilled or nailed. This makes construction easier. Local repairs to the structure can also be attended to as and when required without affecting the rest of the structure [5].

(k) Due to lightweight, their use results in lesser consumption of steel. Composite floor construction using precast unreinforced lightweight concrete blocks and reinforced concrete grid beams (ribs) results in appreciable saving in the consumption of cement and steel, and thereby reduces the cost of construction of floors and roofs considerably. A saving of as much as 15 to 20 per cent in the cost of construction of floors and roofs may be achieved by using this type of construction compared to conventional construction [5].

(l) A better quality control is exercised in the construction of structure with light-weight concrete products owing to use of factory made units [5].

2.1.5 Classification of Lightweight Concretes

Lightweight concrete can also be classified according to the purpose for which it is to be used: distinguished between structural lightweight concrete (ASTM C 330-09), concrete used in masonry units (ASTM C 331-05), and insulating concrete (ASTM C 332-09). This classification of structural lightweight concrete is based on a minimum strenght: according to ASTM C 330-09, the 28-day cylinder compressive strenght should not be less than 17 MPa. The density (unit weight) of such concrete (determined by dry state) should not exceed 1840 kg/m^3, and is usually between 1400 and 1800 kg/m^3. On the other hand, masonry concrete generally has a density between 500 and 800 kg/m^3 and a strength between 7 and 14 MPa. The essential feature of insulating concrete is its coefficient of thermal conductivity which should be below about 0.3 W/mK , whilst density having generally lower than 800 kg/m^3 and strength is between 0.7 and 7 MPa [1].

2.1.6 Application Area of Lightweight Aggregate Concrete

Lightweight aggregate concrete (LWAC) has been used since the ancient periods. Apart from building construction, lightweight aggregate concrete has also been used in ship building, and for thermal insulation. Lightweight aggregates are used in horticulture. The low density of lightweight aggregate concrete made with pumice aggregates results in a reduction in the weight of the structures and the foundations, and in considerable savings in thermal insulation [6].

Lightweight concrete has been widely used in buildings as masonry blocks, wall panels, roof decks and precast concrete units. Reduction in weight by the use of lightweight aggregate concrete is preferred, especially for structures built in seismic zones. Lightweight concrete manufactured either from natural or from artificial aggregate is classified by the ACI Committee 213 into three categories according to its strength and density. The first category is termed low strength, corresponding to low density and is mostly used for insulation purposes. The second category is moderate strength and is used for filling and block concrete. The third category is structural lightweight concrete and is used for reinforced concrete [7].

As states earlier one of the most important applications of lightweight aggregate concrete (LAC) is its utilization as wall block units. The use of LAC has been increasing and has better properties in terms of density and thermal insulation compared with traditional construction materials.

The thermal resistance of LWAC is up to six times that of normal weight concrete. In some designs, when the LWAC is used for exterior wall construction in place of the normal weight aggregate concrete, a substantial reduction in heating cost results. Normally for a 200 mm thick wall, the savings in heating cost in Fredericton, New Brunswick, Canada, over a period of two years, will cover the cost of the lightweight concrete masonry. Also, for a 100 mm brick wall with 25 mm cavity and 200 mm concrete masonry unit, the annual return on the original investment using domestic fuel oil in heating is 32 percent when a normal weight masonry unit is replaced with a lightweight one.

Use of LWAC instead of normal weight concrete (NWC), for example, as a floor salbe in a multi-story building, depends on the relative costs and the potential savings that can ocur by the use of a lighter material. LWAC is about 28 percent lighter than normal concrete and, in a design where the dead load is equal to the live load, a saving of 14 percent in energy intensive steel reinforcement can result. Equal or greater savings are achieved in columns and footings. For long-span bridges, the live load is a minor part of the total load and a reduction in density is translated into reductions is not only mass, but also in section zone. The lower mass and density are extremely important in seismic areas where a reduction in the initial effects of the dead load may mean the difference between section survival and section failure [6].

2.2 Pumice

2.2.1 Description of Pumice

Pumice is a volcanic origin natural material. As technical terminology pumice stone is known as a natural lightweight aggregate.

According to TS 3234 pumice defined as:

- Volcanic origin natural lightweight aggregate
- Contains up to 80% air voids
- Voids disconnected with each other
- Sponge looking
- Silicate essential
- Unit weight usually less than 1gr/cm^3
- Specific gravity generally more than 2.1gr/cm^3
- Mohs hardness scale is around 5.5-6.0
- Glassy texture
- Contains no crystal water [8]

Pumice is formed by the release of gases during the solidification of lava. The cellular structure of pumice is created by the formation of bubbles or air voids when gases contained in the molten lava flowing from volcanoes become trapped on cooling. The cells are elongated and parallel to one another and are sometimes interconnected. Due to formation process pumice stones contains up to 80% air voids. Pumice possess very high porosity and it is also named as volcanic rock glass [8].

Pumice contains up to 75 percent silisium dioxide (SiO_2) in chemical composition. As general the chemical composition of pumice as follows:

- 45% - 75% SiO_2
- 13% - 21% Al_2O_3
- 1% - 7% Fe_2O_3
- 1% - 11% CaO
- 7% - 9% Na_2O- K_2O

SiO_2 composition in the rock causes to gain abrasiveness property. As for composition of Al_2O_3 causes to gain fire and heat resistance property of the rock.
Pumice Stone classified as a two different category according to formation mechanisms during volcanic activity. These are:

- Asidic characteristic pumice
- Basaltic characteristic pumice

In both category, they contain very high range of porosities. Density of asidic pumice stone is in range of 500 – 1000 kg/m^3. Density of basaltic pumice stone is generally in the range of 1000- 2000 kg/m^3. This shows that density of asidic magma is lower compared with basaltic magma. In addition, asidic characteristic pumice is most commonly available rock sources in terms of pumice type in the world [8].

The chemical composition of asidic and basaltic pumice are shown in Table 2.1:

Table 2.1: Chemical Composition of Asidic and Basaltic Pumice

Chemical Composition	**Asidic Pumice**	**Basaltic Pumice**
SiO_2	70%	45%
Al_2O_3	14%	21%
Fe_2O_3	2.50%	7%
CaO	0.90%	11%
MgO	0.60%	7%
$Na_2O + K_2O$	9.00%	8%

As can be seen in chemical composition of asidic and basaltic pumice, it can be said that asidic pumice contains higher silisium compared with basaltic pumice. For the reason asidic pumice is more suitable and desirable raw material as used in construction material due to highly tends to puzzolanic activity.

The specific gravity of pumice stone is generally more than 2.1 gr/cm^3. Increasing the particle size of pumice aggregate causes to decrease in density. In other words, smaller size of particles causes to increase the density of material. On the other hand increasing the particle size of aggregate causes to increase the percentage porosities in the aggregate [8].

Table 2.2: Dry Unit Weight of Pumice with respect to Particle Size.

Range of Particle size (mm)	**Dry Unit Weight (kg/m^3)**
≥32	319 ± 5%
16 - 32	408± 5%
8 - 16	502± 5%
4 - 8	594± 5%
2 - 4	688± 5%
1 - 2	780± 5%
0.5 - 1	873± 5%
0.25 - 0.5	966± 5%

Table 2.3: Percentage of Real Porosity of Pumice with respect to Particle Sizes.

Range of Particle size (mm)	**Real Porosity (%)**
≥32	86.29 ± 3%
16 - 32	82.47± 3%
8 - 16	78.43± 3%
4 - 8	74.47± 3%
2 - 4	70.43± 3%
1 - 2	66.48± 3%
0.5 - 1	62.48± 3%
0.25 - 0.5	58.49± 3%

Photo 2.1: Pumice Stone

Photo 2.2: Pumice Aggregate

Consequently pumice aggregate is a volcanic origin industrial raw material that used since long time before in many different international industrial sectors [8].

2.2.2 Pumice Deposits and Reservoirs

Totally 18 billion m^3 pumice stone are available in the world. The most important countries can be counted as, Italy, Spain, Turkey, Germany, USA, Greece, Iran, Guadeloup, Martinique and Dominic Republic. Especially Turkey possesses a very big potential in terms of pumice deposits. It can be said that around 40 percent of the total pumice reservoirs are available in Turkey. It is forecasted that 7.4 billion m^3 of pumice stone out of 18 billion m^3 are in Turkey. This shows that Turkey is in important position in terms of world pumice reservoirs. Nowadays pumice stones are exported from Turkey to nearly thirty different countries. Most of the demands are from textile sector [10].

Table 2.4: Pumice Production with respect to Countries

Country	**Pumice Production (Ton/Year)**
Italy	5.600.000
Greece	1.950.000
Turkey	1.650.000
Spain	800.000
Germany	800.000
France	680.000
Dominic	300.000
Others	4.670.000
Total	**16.450.000**

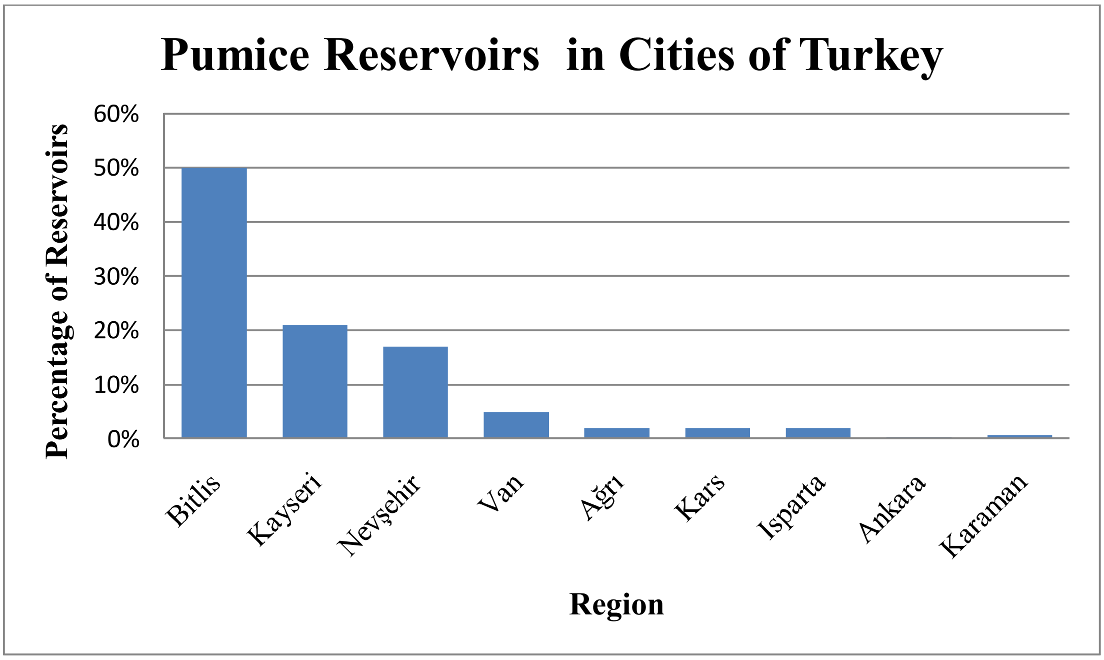

Figure 2.1: Distribution of Percentage of Pumice Reservoirs with respect to Region in Turkey [8].

2.2.3 Usage Area of Pumice

As it is well known, pumice is used as a raw material in many industrial sectors. Construction sector is the main sector in terms of usage of pumice as a raw material in the world as well as in N.Cyprus. The main usage area of pumice are:

1- Construction Sector

2- Textile Sector

3- Agricultural Sector

4- Chemical Sector

5- Other Industrial and Technological Areas [8].

In Turkey, approximately 1250000 ton/year of pumice are used in construction sector in order to manufacture lightweight construction material. Very few amount is used in other sectors in Turkey and N.Cyprus. However, the amount of consumption is not in its desired level compared with the consumption level of other countries [8].

Table 2.5: Distribution of Percentage of Pumice Consumption with respect to Sectors

Sectors	**Pumice Consumption in World (%)**	**Share of Pumice consumption in Turkey (%)**
Construction Sector	72	8
Textile Sector	5	65
Agricultural Sector	4	5
Chemical Sector	7	3
Other Sectors	12	2

As can be seen in above table, the main consumption area of pumice is construction sector in the world as well as in Turkey. In spite of fact that this consumption level is not in desired level by taking account of reservoir potential in Turkey.

2.2.4 Usage of Pumice In Construction Sector

There is extensive usage area to use pumice in construction sector depending on characteristic properties of pumice. The reasons to be preferred of pumice to use as a raw material in construction sector are as follows:

- Low unit volume weight
- High thermal and sound insulation
- High resistance to fire
- High resistance to freeze-thaw effects
- High resistance to climatic effect
- Perfect acoustic property

Usage of Pumice in construction Industry can be categorized mainly in four different areas [11].

2.2.4.1 Lightweight Construction Element

The main extensive usage area of pumice as a raw material is to produce lightweight construction element in the World and N.Cyprus as well. Lightweight construction elements can be classified in 3 main groups in terms of industrial usage. These are:

- Reinforced masonry blocks
- Full or spaced unreinforced masonry blocks
- Filler block in joint-floors [11].

2.2.4.2 Prefabricated Lightweight Construction Elements

Prefabricated lightweight construction elements are produced in many countries in Europe and America for a long time however it is in beginner stage in Turkey. Prefabricated lightweight construction element produced by pumice can be categorize in 3 main group as follows:

- Massive places (cabins, garages)
- Entegrated places (houses, workplaces, leisure centres)

- Wall panel and slab elements [11].

2.2.4.3 Ready-Mixed Lightweight Mortar and Plaster

Nowadays, the usage of ready-mixed mortar/plaster products are increases remarkable in construction sector. Lightweight mortar and plaster provide serious advantages to the building due to its characteristic properties. The main properties are:

- Lightweight (reduction in load)
- High thermal and sound insulation
- Perfect acoustic property

Due to above reasons, ready-mixed lightweight pumice mortar/plaster products comprises a vital market space in construction sector [11].

In this thesis, especially the usage of pumice aggregate in mortar and plaster are investigated and compared with traditional mortar/plaster made with limestone aggregate. Related experimental studies and analysis of results are explained in detail in the following chapters.

2.2.4.4 Production of Lightweight Pumice Concrete

In many countries, althought there are extensive usage area to use pumice in concrete industry in the world, however it is not in desired level in Turkey and N.Cyprus. In the world, the main usage area of lightweight pumice concrete are:

- One story residential building
- Boundary wall where noise pollition is higher especially in airports
- Concert, theater, disco ,cinema hall

The main reasons to use lightweight pumice concrete are as follows:

-Unit volume weight is usually 1/2 – 2/3 of normal weight concrete (reduction in dead load).

Reduction in dead load causes gives serious advantages to the buildings, These are:

- Dispose in range of 13% - 17% in reinforcing steel
- Decrease in size of structural element sections such as beams, columns
- Dispose around 30 % in workmanship [11].

Pumice aggregates combined with Portland cement and water produces a lightweight thermal and sound insulating, fire-resistant lightweight concrete for roof decks, lightweight floor fills, insulating structural floor decks, curtain wall system, either prefabricated or in situ, pumice aggregate masonry blocks and a variety of other permanent insulating applications [12].

Moreover the thermal conductivity of normal concrete is around 2 W/mK. This shows that lightweight pumice aggregate possesses higher thermal insulation capacity compared with normal weight concrete. It is clear that lightweight pumice concrete provides 4 - 6 times higher thermal insulation performance compared with normal concrete [12].

Increasing utilisation of lightweight materials in civil engineering structure applications is making pumice stone a very popular raw material as a lightweight rock. Due to having a good ability for making the different products based on its physical, chemical and mechanical properties, the pumice aggregate finds a large using area in civil industry as a construction material. In order to design an initial stage of a building project, the construction material properties should be well evaluated. Therefore, the need arises to analyse the materials to be used in construction experimentally in detail. This forms the backbone of any material analysis models in engineering applications. Lightweight concrete is used in civil engineering field, as filler or for the manufacture of heat and sound insulation elements such as panels, masonries, partitions as well as load bearing structural elements [12].

It is a common use to apply lightweight concrete (LWC) for both structural and non-structural applications. As a structural material it should have specific characteristics to meet the strength and performance requirements for the application. Thus, naturally, before recommending any material for a specific application (whether structural or non-structural) there is a need to study the mechanical characteristics to establish its suitability [12].

2.3 Pumice Block

2.3.1 Description of Pumice Blocks

The most common construction material produced by pumice aggregate is pumice-block. Pumice-block is a general name of masonry elements manufactured by mixing of pumice aggregate, cement, and water [8].

The use of lightweight aggregate with low thermal conductivity in the production of lightweight concrete blocks can provide an alternative cost-effective solution. With a large number of voids in the aggregate, lightweight aggregate concrete possesses a relatively higher thermal insulating efficiency than the normal concrete. Therefore, lightweight concrete has superior properties such as lightness in weight, and good thermal insulation, but has a disadvantage of low mechanical properties which makes them suitable only as non-load bearing walls [12].

Due to the high porosity and low bulk density, pumice was used as a natural lightweight aggregate in the production of low-strength concrete such as masonry units making purposes [12].

The production of lightweight concrete block in most countries is done by a highly mechanised industry based on great automation and accuracy. This production has to match strict standards that describe properties specified for the products. These may include denotations on sizes, strength, weather resistance, insulating properties and fire resistance. In recent years, there has been focus on utilising pumice aggregates in Turkey as the most popular natural lightweight aggregate in the manufacturing of lightweight concrete blocks. Pumice aggregate can be used as aggregates in concrete that meets all these requirements [12].

Pumice lightweight concrete blocks (PLWCB) are made of pumice, cement and water which are used in construction of non-load bearing infill walls and slabs. The outstanding physical properties of PLWCB have been demonstrated over the years. The concrete block process is perceived to be one of the most labour intensive aspects of construction today. Since these must be handled and placed one-by-one, increased mason productivity is the key to effective management of masonry construction. In tests conducted both in the field and at the University Research and Development Laboratory, it has been dramatically shown that the size and weight of LWC blocks are primary factors influencing the speed at which blocks can be laid [13].

One of the most effective ways to reduce the dead load in multi storey buildings is to lighten the weight of the structure. Pumice lightweight concrete blocks (PLWCB) can be manufactured from a density range of 400–1300 kg/m^3 [13].

Nowadays, the annual consumption of pumice in order to produce pumice-block is more than 20 million m^3 in world construction sector [8].

Photo 2.3: Pumice Block Masonry Unit

The characteristic properties of pumice aggregate such as physical, and chemical properties are the essential factors that can influence the quality of pumice-block products. Moreover the aggregate grading, production technology and mix proportions can be critical factors in terms of characteristic properties of pumice block [8].

2.3.2 Pumice-Block Production Process

Pumice-blocks are produced from pumice concrete. As mentioned before pumice concrete is a kind of lightweight concrete manufactured by mixing of pumice aggregate, cement, and water. Fresh pumice concrete is casted into moulds under high pressure and vibration to give specific shapes to the block. All these systems are under computer conctrol. After air curing is applied to the blocks for gain required strenght and finally the product is ready to use in construction [8].

Photo 2.4: Pumice-Block Production Machine

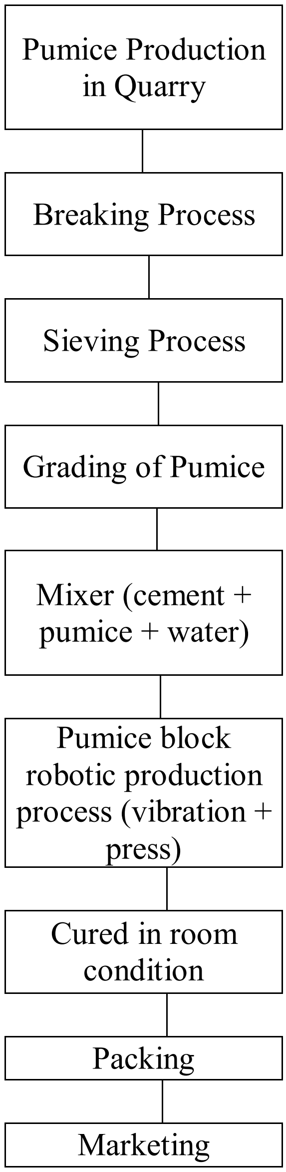

Figure 2.2: Symbolic Schema of Pumice Block Production Process

Main Mix proportions of pumice blocks are as follows:

- Volume of mixer process: 1500 liter
- Amount of pumice aggregate(Oven dry): 1600 kg
- Cement (P.C 42.5) : 220 kg
- Colour pigment: 1 kg
- Amount of water: 220 kg [8].

2.3.3 Products of Pumice Block

In construction sector, pumice-block products is preferred to be used more than sixty different usage area. The main reasons are listed below:

- Lightweight
- High thermal and sound insulation performance
- High resistance to climatic effect
- Perfect bonding with plaster

According to TS 2823 pumice-block products are categorized in two main groups. These are:

1- Reinforced pumice blocks
2- Unreinforced pumice blocks

Products of reinforced pumice blocks are classified according to usage area and sizing as follows:

- Doors and windows lintel
- Floor blocks
- Roof blocks
- Vertically wall elements
- Horizontally wall elements

According to usage area and geometrical shapes, unreinforced pumice blocks products are classified as follows:

- Hollow masonry blocks
- Filled masonry blocks
- Solid masonry units
- Filled block (ceiling block)

In above classifications the "hollow masonry blocks" and " filled masonry blocks" are produced in four different shapes as follows:

1- Single file hollow pumice-block
2- Double file hollow pumice-block
3- Three file hollow pumice-block
4- Four file hollow pumice-block

Nominal dimensions of pumice blocks are shown in Figure 2.3.

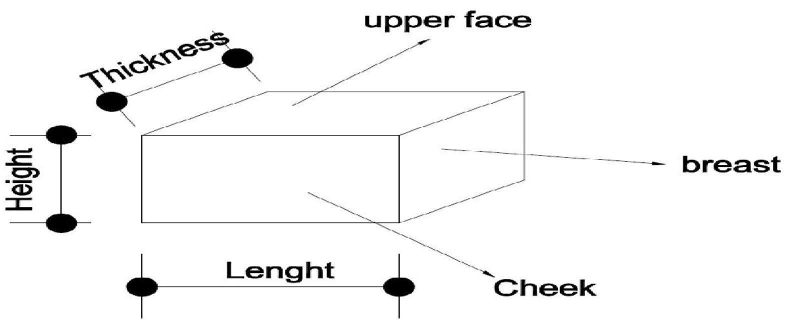

Figure 2.3: Nominal Dimensions and Surfaces of Pumice-block

Symbolic dimensions used in design of pumice blocks are shown in Figure 2.4

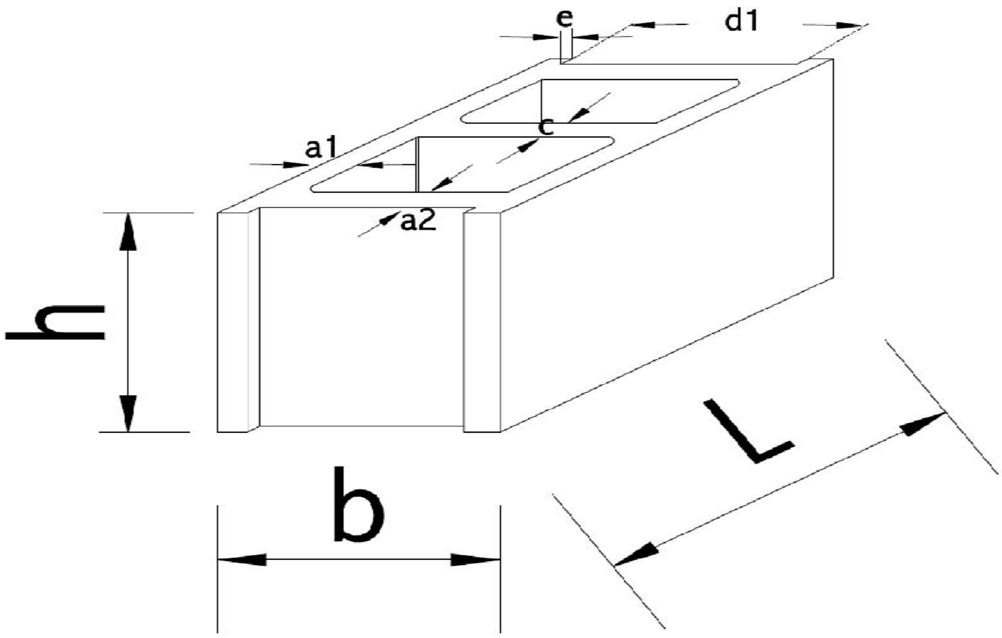

Figure 2.4: Symbolic Dimensions of Pumice Block

Where

L: Length

b: Thickness

h: Height

a1: Longitudinal exterior wall thickness

c: Interior wall thickness

d1: Breast mortar length

e: Breast mortar thickness

a2: Crosswise exterior wall thickness

According to TS 2823, 190 mm must be the maximum thickness in single and double file hollow type of pumice blocks. In three file hollow type of pumice blocks the thickness must be between 200 mm-300 mm. Besides the thickness must be more than 300mm in four file hollow type of pumice blocks. Additionally the thickness of base coating must be designed as a minimum 10 mm [8].

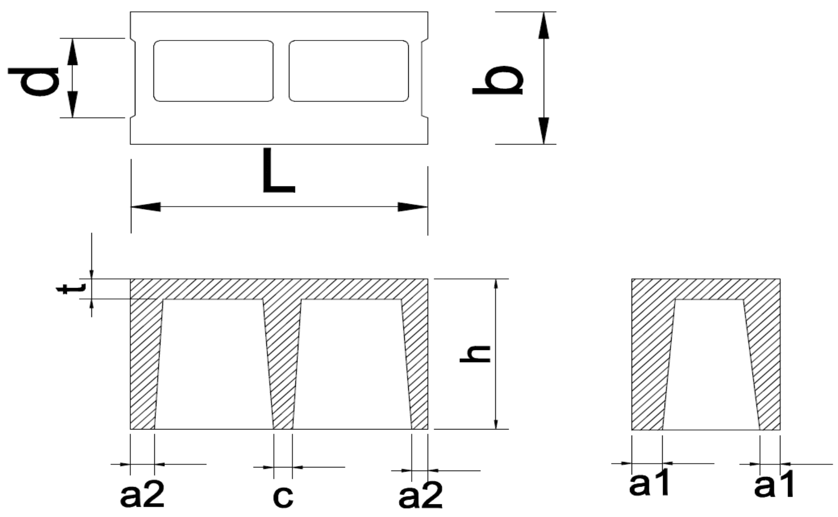

Figure 2.5: Single File Hollow Pumice Block

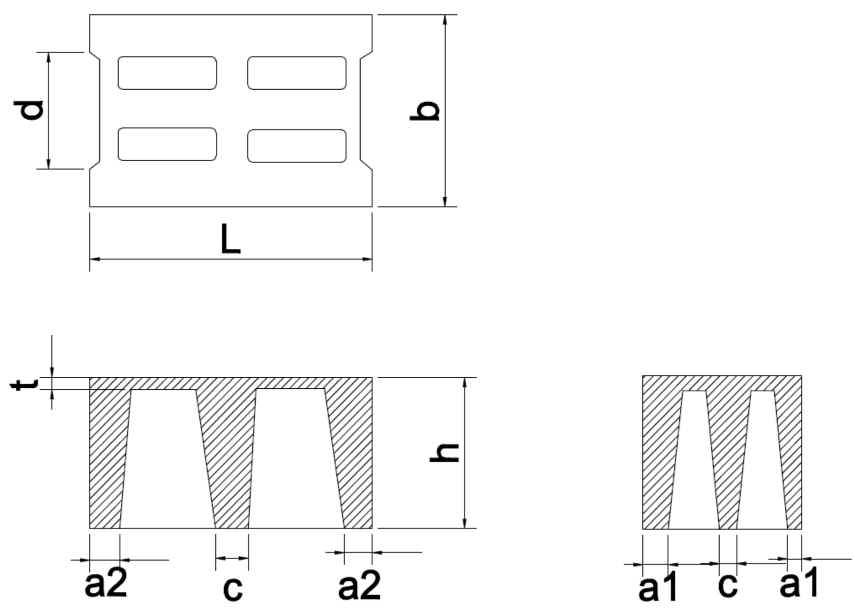

Figure 2.6: Double File Hollow Pumice Block

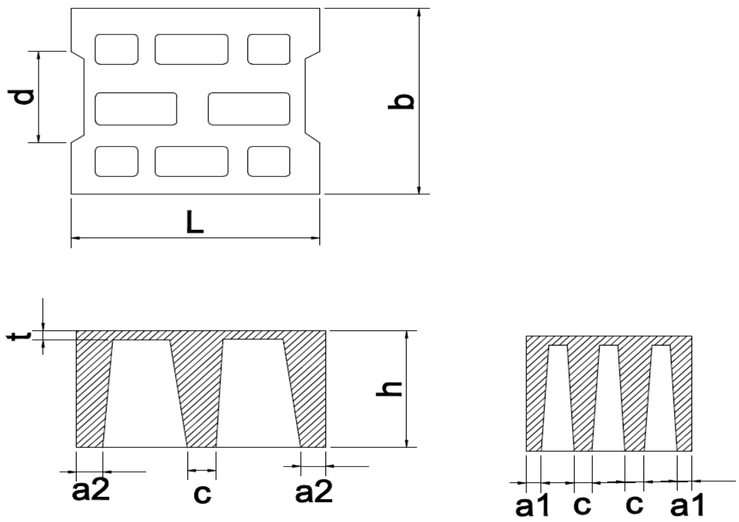

Figure 2.7: Three File Hollow Pumice Block

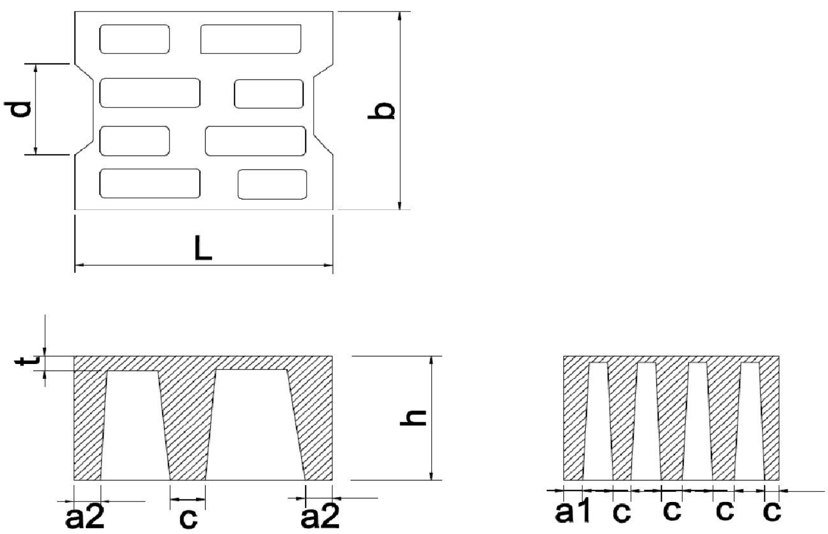

Figure 2.8: Four File Hollow Pumice Block

Table 2.6: Nominal and Design Dimesions of Unreinforced Hollow Pumice Blocks

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<tr><th colspan="3">Dimensions</th><th rowspan="3">Hollow type and number</th><th colspan="2">Exterior Wall Thickness</th><th rowspan="3">Interior Wall Thickness min c</th></tr>
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<tr><td>365</td><td>490/240</td><td>30</td><td>30</td><td>30</td></tr>
</table>

Note: All dimensions are in millimeter.

2.3.4 Benefits of Using Pumice-Blocks in Buildings

2.3.4.1 Lightweight Structures

As mentioned before, the density of pumice concrete is lower compared with normal concrete. Density of pumice concrete is in the range of 250-1500 kg/m^3. However density of normal concrete is around 2400 kg/m^3. It is clear that usage of pumice aggregate causes reduction of concrete density. As a result reduction in dead load of the structure, less load will be transmitted to the ground, therefore, soil setting will became as minimum as possible [8].

The other important influence is the performance of structure against earthquake forces. As it is well known , lighther structures shows beter resistance and flexibility during earthquake. It is very simple to explain the influence of weight against any kind of force by famous Newton Theory. Newton Theory says that:

$$F = (m) \times (a) \quad (2.1)$$

Where:

F: Horizontal force (N)

m: Mass (kg)

a: Acceleration (m/s^2)

In Equation 2.1, it is clear that increasing the mass will result larger forces acting on the object. Consequently it can be said that reduction in dead load of structure results better performance against earthquake forces.

2.3.4.2 Economical Structures

It is well known that loads are the most important factor in designing of structural elements (static system) such as colums and beams in the building. Reduction in loads causes to design smaller size of structural elements and as a result of this section of elements became smaller. Moreover some researchers reported that use of pumice block in building resulted reduction in load at the rate of 1/3 of the total loads. As a result of this, around 17 percent of saving has been achieved in terms of reinforcing steel in the elements [8].

2.3.4.3 Thermal Insulation

As mentioned before, thermal conductivity of pumice concrete is usually 4-6 times less compared with normal concrete due to characteristic properties of aggregates. Because of this features a large amount of energy saving can be achieved in buildings [8].

2.3.4.4 Sound Insulation

Pumice blocks exhibits perfect acoustic property. It is well known that solid materials are transmitted sound waves faster than looser (less concentrated) materials. The air voids prevent diffusion of sound waves within material. Some researchers reported that desibel level is reduced from 75 to 55 in a job environment. As a result of this, 25 percent of employer performance has been enhanced.

2.4 Mortars

2.4.1 General

In masonry construction, mortar constitutes only a small proportion (approximately 7 percent) of the total wall area, but its influence on the performance of the wall is significant. At a first glance, mortar gives the appearance of simply being a jointing material for masonry units. Althought the primary purpose of mortar in masonry is to bond masonry units into an assemblage, which acts as an integral element having desired functional characteristics, mortar also serves other functions [16]:

1. Bonds masonry units together into an integral structural assembly
2. Seals joints against penetration by air and moisture
3. Accommodates small movements within a wall
4. Bonds to joint reinforcement to asist in resisting shrinkage and tension
5. Bonds to ties and anchors so that all elements perform as an integral unit [16].

Portland cement concretes and masonry mortars contain some of the same principal ingredients, it is often erroneously assumed that good concrete practice is also good mortar practice. Realistically, mortars differ from concrete in working consistencies, in methods of placement and in the curing environment. Masonry mortar is commonly used to bind masonry units into a single structural element, while concrete is usually a structural element in itself [14].

A major distinction between the two materials is illustrated by the manner in which they are handled during construction. Concrete is usually placed in nonabsorbent metal or wooden forms or otherwise treated so that most of the water will be retained. Mortar is usually placed between absorbent masonry units, and as soon as contact is made the mortar loses water to the units. Compressive strength is a prime consideration in concrete, but it is only one of several important factors in mortar [14].

2.4.2 Properties of Mortars

Masonry mortars have two distinct and important sets of properties, the plastic mortars and hardened mortars. Plastic properties determine a mortar's construction suitability, which in turn relate to the properties of the hardened mortar and, hence, of finished structural elements. Properties of plastic mortars that help determine their construction suitability include workability and water retentivity. Properties of hardened mortars that help determine the performance of the finished masonry include compressive strenght, bond and durability [14].

2.4.2.1 Plastic Mortars

2.4.2.1.1 Workability

Workability is the most important property of plastic mortar. Workable mortar can be spread easily with a trowel into the separations and cracks of the masonry unit.

Workable mortar also supports the weight of masonry units when placed and facilitates alignment. It adheres to vertical masonry surfaces and readily extrudes from the mortar joints when the mason applies pressure to bring the unit into alignment. Workability is a combination of several properties, including plasticity, consistency, cohesion, and adhesion, which have defied exact laboratory measurement. The mason can best assess workability by observing the response of the mortar to the trowel.

2.4.2.1.2 Water Retention and Water Retentivity

Water retention is a measure of the ability of a mortar under suction to retain its mixing water. This property gives the mason time to place and adjust a masonry unit without the mortar stiffening.Water retentivity is increased through higher lime or air content, addition of sand fines within allowable gradation limits, or use of water retaining materials.

2.4.2.1.3 Stiffening Characteristics

Hardening of plastic mortar relates to the setting characteristics of the mortar, as indicated by resistance to deformation. Initial set as measured in the laboratory for cementitious materials indicates extent of hydration or setting characteristics of neat cement pastes. Too rapid stiffening of the mortar before use is harmful. Mortar in masonry stiffens through loss of water and hardens through normal setting of cement. This transformation may be accelerated by heat or retarded by cold. A consistent rate of stiffening assists the mason in tooling joints [14].

2.4.2.2 Hardened Mortars

2.4.2.2.1 Compressive Strength

The compressive strength of mortar is sometimes used as a principal criterion for selecting mortar type, since compressive strength is relatively easy to measure, and it commonly relates to some other properties, such as tensile strength and absorption of the mortar.

The compressive strength of mortar depends largely upon the cement content and the water-cement ratio. Compressive strength of mortar increases with an increase in cement content and decreases with an increase in lime, sand, water or air content. Retempering is associated with a decrease in mortar compressive strength. The amount of the reduction increases with water addition and time between mixing and retempering. It is frequently desirable to sacrifice some compressive strength of the mortar in favor of improved bond, consequently retempering within reasonable time limits is recommended to improve bond.

Compressive strength should not be the sole criterion for mortar selection. Flexural strength is also important because it measures the ability of a mortar to resist cracking. Mortars should typically be weaker than the masonry units, so that any cracks will occur in the mortar joints where they can more easily be repaired.

2.4.2.2.2 Bonding

Bond actually has three sections; strength, extent and durability. Because many variables affect bond, it is difficult to devise a single laboratory test for each of these categories that will consistently yield reproducible results and which will approximate construction results. These variables include air content and cohesiveness of mortar, elapsed time between spreading mortar and laying masonry unit, suction of masonry unit, water retentivity of mortar, pressure applied to masonry joint during placement and tooling, texture of masonry unit's bedded surfaces, and curing conditions.

The tensile and compressive strength of mortar far exceeds the bond strength between the mortar and the masonry unit. Mortar joints, therefore, are subject to bond failures at lower tensile or shear stress levels. A lack of bond at the interface of mortar and masonry unit may lead to moisture penetration through those areas. Complete and intimate contact between mortar and masonry unit is essential for good bond. This can best be achieved through use of mortar having proper composition and good workability, and being properly placed.

2.4.2.2.3 Extensibility and Plastic Flow

Extensibility is maximum unit tensile strain at rupture. It reflects the maximum elongation possible under tensile forces. Low strength mortars, which have lower moduli of elasticity, exhibit greater plastic flow than their high moduli counterparts at equal paste to aggregate ratios. For this reason, mortars with higher strength than necessary should not be used. Plastic flow or creep will impart flexibility to the masonry, permitting slight movement without apparent joint opening.

2.4.2.2.4 Durability

The durability of relatively dry masonry which resists water penetration is not a serious problem. The coupling of mortars with certain masonry units, and design without exposure considerations, can lead to unit or mortar durability problems. It is generally conceded that masonry walls, heated on one side, will stand many years before requiring maintenance, an indication of mortar's potential longevity. Parapets, masonry paving, retaining walls, and other masonry exposed to freezing while saturated represent extreme exposures and thus require a more durable mortar [14].

2.4.3 Composition and its Effect on Properties:

Essentially, mortars contain cementitious materials, aggregate and water. Sometimes admixtures are used also.

Each of the principal constituents of mortar makes a definite contribution to its performance. Portland cement contributes to strength and durability. Lime, in its hydroxide state, provides workability, water retentivity, and elasticity. Both portland cement and lime contribute to bond strength. Instead of portland cement-lime combinations, masonry cement or mortar cement is used. Sand acts as a filler and enables the unset mortar to retain its shape and thickness under the weight of subsequent courses of masonry. Water is the mixing agent which gives fluidity and causes cement hydration to take place. Mortar should be composed of materials which will produce the best combination of mortar properties for the intended service conditions [14].

2.4.3.1 Cementitious Materials Based on Hydration

Portland cement, a hydraulic cement, is the principal cementitious ingredient in most masonry mortars. Portland cement contributes strength to masonry mortar, particularly early strength, which is essential for speed of construction. Straight portland cement mortars are not used because they lack plasticity, have low water retentivity, and are harsh and less workable than portland cement-lime or masonry cement mortars.

Masonry cement is a proprietary product usually containing portland cement and fines, such as ground limestone or other materials in various proportions, plus additives such as air entraining and water repellency agents.

Mortar cement is a hydraulic cement similar to masonry cement, but the specification for mortar cement requires lower air contents and includes a flexural bond strength requirement [14].

2.4.3.2 Cementitious Materials Based on Carbonation

Hydrated lime contributes to workability, water retentivity, and elasticity. Lime mortars carbonate gradually under the influence of carbon dioxide in the air, a process slowed by cold, wet weather. Because of this, complete hardening occurs very slowly over a long period of time. This allows healing, the recementing of small hairline cracks.

Lime goes into solution when water is present and migrates through the masonry where it can be deposited in cracks and crevices as water evaporates. This could also cause some leaching, especially at early ages. Successive deposits may eventually fill the cracks. Such autogenous healing will tend to reduce water permeance.

Portland cement will produce approximately 25 % of its weight in calcium hydroxide at complete hydration. This calcium hydroxide performs the same as lime during carbonation, solubilizing, and redepositing [14].

2.4.3.3 Aggregates

Aggregates for mortar consist of natural or manufactured sand and are the largest volume and weight constituent of the mortar. Sand acts as an inert filler, providing economy, workability and reduced shrinkage, while influencing compressive strength. An increase in sand content increases the setting time of a masonry mortar, but reduces potential cracking due to shrinkage of the mortar joint. The special or standard sand required for certain laboratory mortar tests may produce quite different test results from sand that is used in the construction mortar.

Well graded aggregate reduces separation of materials in plastic mortar, which reduces bleeding and improves workability. Sands deficient in fines produce harsh mortars, while sands with excessive fines produce weak mortars and increase shrinkage. High lime or high air content mortars can carry more sand, even with poorly graded aggregates, and stil provide adequate workability.

Field sands deficient in fines can result in the cementitious material acting as fines. Excess fines in the sand, however, is more common and can result in oversanding, since workability is not substantially affected by such excess.

Unfortunately, aggregates are frequently selected on the basis of availability and cost rather than grading. Mortar properties are not seriously affected by some variation in grading, but quality is improved by more attention to aggregate selection. Often gradation can be easily and sometimes inexpensively altered by adding fine or coarse sands. Frequently the most feasible method requires proportioning the mortar mix to suit the available sand within permissible aggregate ratio tolerances, rather than requiring sand to meet a particular gradation [14].

2.4.3.4 Water

Water performs three functions. It contributes to workability, hydrates cement, and facilitates carbonation of lime. The amount of water needed depends primarily on the ingredients of the mortar.Water should be clean and free from injurious amounts of any substances that may be deleterious to mortar or metal in the masonry. Usually, potable water is acceptable.

Water content is possibly the most misunderstood aspect of masonry mortar, probably due to the confusion between mortar and concrete requirements. Water requirement for mortar is quite different from that for concrete where a low water/cement ratio is desirable. Mortars should contain the maximum amount of water consistent with optimum workability. Mortar should also be retempered to replace water lost by evaporation [14].

2.4.3.4 Admixtures

Admixtures for masonry mortars are available in a wide variety and affect the properties of fresh or hardened mortar physically or chemically. Some chemical additions are essential in the manufacture of basic mortar materials. The inclusion of an additive is also necessary for the production of ready mixed mortars. Undoubtedly there are also some special situations where the use of admixtures may be advantageous when added at the job site mixer. In general, however, such use of admixtures is not recommended. Careful selection of the mortar mix, use of quality materials, and good practice will usually result in sound masonry [14].

Mortar admixtures are materials which are added to mortar mix, usually in small amounts, to achieve a particular result. The results may include the following:

-Increased workability

-Added color

-A stronger bond between the mortar and masonry units

-An acceleration in setting time [15].

Little information has been published regarding the effect of admixtures on mortar bond or strength. However, experience on various jobs has indicated undesirable results may ocur in some instances. Air entrainment, for example, has a definite detrimental effect on the bond between mortar and the unit. Admixtures should never be used unless they are definitely specified in the contract and the manufacturer's mixing directions are followed exactly [15].

2.4.3.4.1 Air-Entraining Agents

Air-entraining agents are used in masonry cement mortar to increase its resistance to freezing and thawing, therby increasing the life and durability of the mortar. The air-entraining admixture traps microscopic air bubbles in the mix. These air bubbles allow the mortar to conctract and expand. When freezing and thawing ocur, the mortar is less likely to crack and break. Mortar also has a tendency to hold water longer when an air-entraining additive is used, therby increasing workability of the mix.

Mortar with air conctent over 12% by volume will weaken the bond strenght of the mortar mix [15].

2.4.3.4.2 Color

Color can be added to mortar using selected aggregates or inorganic pigments. Inorganic pigments should be of mineral oxide composition and should not exceed 10 % of the weight of Portland cement, with carbon black limited to 2 %, to avoid excessive strength reduction of the mortar. Pigments should be carefully chosen and used in the smallest amount that will produce the desired color. To minimize variations from batch to batch it is advisable to purchase cementitious materials to which coloring has been added at the plant or to use preweighed individual packets of coloring compounds for each batch of mortar, and to mix the mortar in batches large enough to permit accurate batching. Mortar mixing procedures should remain constant for color consistency [14].

2.4.4 Kinds of Mortars

2.4.4.1 History

History records that burned gypsum and sand mortars were used in Egypt at least as early as 2690 B.C. Later in ancient Greece and Rome, mortars were produced from various materials such as burned lime, volcanic tuff, and sand. When the first settlements appeared in North America, a relatively weak product was still being made from lime and sand. The common use of portland cement in mortar began in the early part of the twentieth century and led to greatly strengthened mortar, either when portland cement was used alone or in combination with lime. Modern mortar is still made with from portland cement and hydrated lime, in addition to mortars made from masonry cement or mortar cement [14].

2.4.4.2 Classification

Two main classifications of mortars should become familiar with are portland cement-hydrated lime mortars and masonry cement mortars.

Portland cement-hydrated lime mortars are a combination of portland cement, hydrated lime, sand, and water. Depending on the proportions of the materials in the mix, the mortars will have different strengths and properties [15].

Cement-lime mortars have a wide range of properties. At one extreme, a straight portland cement and sand mortar would have high compressive strength and low water retention. A wall containing such a mortar would be strong but vulnerable to cracking and rain penetration. At the other extreme, a straight lime and sand mortar would have low compressive strength and high water retention. A wall containing such a mortar would have lower strength, particularly early strength, but greater resistance to cracking and rain penetration. Between the two extremes, various combinations of cement and lime provide a balance with a wide variety of properties, the high strength and early setting characteristics of cement modified by the excellent workability and water retentivity of lime [14].

Masonry cement mortars are popular in masonry construction today because they come prepackaged. The mason needs to add only sand and water on the job. Correct proportions of sand and water are essential if masonry cement mortar is to meet standard specification of ASTM C270. Masonry cement mortar has certain additives to provide workability, flexibility, and water-retention properties. One major complaint of architects and engineers is that the proportions of these additives are not printed on the bag. Portland cement- lime mortars can be mixed in exact proportions to meet specifications and, therefore, be the correct mortar for a particular job. One mortar is not necessarily beter than the others. However, the mason should be aware of the two main classifications of mortars used in masonry construction [15].

2.4.4.2.1 Portland Cement-Hydrated Lime Mortars

The Brick Industry Association (BIA), the leading authority on brick masonry in the United States, has developed the following specifications for mortars used in the construction of masonry work. Four types of portland cement-lime mortars are covered under BIA Designation M1-72. The following is a description of the four types and their uses [15].

2.4.4.2.2 Recomended Uses of Mortars

2.4.4.2.2.1 Type N

Type N is the mortar most often used. Type N is a medium-strenght mortar suitable for general use in exposed masonry above grade and where high compressive or lateral masonry strength are required. It is specially used for the following:

- Parapet walls (that portion of a wall which extends above the roof line, usually used as a fire wall)
- Chimneys
- Exterior walls exposed to severe weather.

Type N mortar has a compressive strength of at least 5.25 N/mm^2 after being cured for 28 days. When mixed, prebagged cement mortars sold under various brand names should conform to a mortar, like Type N, or at least medium strength [15].

2.4.4.2.2.2 Type M

Type M mortar has a higher compressive strength (at least17.5 N/mm^2 in 28 days) and somewhat greater durability than some of the other types. It is especially recommended for masonry which is below grade and in contact with the earth, such as foundations, retaininng walls, walks, sewers, and manholes. It will also withstand severe frost action and high-lateral loads imposed by pressure from the earth [15].

2.4.4.2.2.3 Type S

Type S mortar is recommended for use in reinforced masonry and for standard masonry where maximum flexural strength is required. It is also used when mortar is the sole bonding agent between facing and backing units. Type S mortar has a fairly high compressive strength of at least 12.6 N/mm^2 in 28 days [15].

2.4.4.2.2.4 Type O

Type O mortar is a low-strength mortar suitable for general interior use in walls that do not carry a great load. It may be used for a load-bearing wall of solid masonry. However, it may only be used in those walls in which the axial compressive strength developed do not exceed 0.7 N/mm^2, and which will not be subjected to weathering or to freezing temperatures. The compressive strength of Type O mortar should be at least 2.5 N/mm^2 [15].

2.4.4.3 Proportions

Each type of Portland cement-lime mortar should be mixed in proportions shown in Table 2.7

Table 2.7: Mix Proportion of Mortar by Volume

Mortar Type	Parts by volume of Portland cement	Parts by volume of hydrated lime	Parts by volume of sand in loose condition
M	1	1/4	Not less than 2, 1/4 and not more than 3 times the sum of the volume of cement and lime used.
S	1	1/2	
N	1	1	
O	1	2	

A recent improvement in some areas of the country in portland-lime cement is the introduction to the market of portland-lime cement mortar blended together in one bag and needing only sand and water to be added to form mortar [15].

2.4.4.4 Selection of the Right Mortar Type

There is no single mortar mix that is uniquely suitable for all applications. No mortar type rates the highest in all areas of applications. No single mortar property defines mortar quality. Therefore, it is very important to understand the selection of the right type of mortar as it influences both the construction process and the quality of finished products. ASTM Standard specifications provide a means for specifications to identify acceptable materials and products without limiting those items to specific brands of manufactures. Project specifications should reference ASTM C270, the standard specification for Mortar of Unit Masonry [16].

The different mortar types are used for a variety of masonry applications. Type N mortar is a general-purpose mortar that provides good workability and serviceability. It is commonly used for interior walls, above-grade exterior walls under normal conditions, and for veneers. Type S mortar is used for structural load-bearing applications and for exterior applications for at or below grade. In addition, it also provides increased resistance to freeze-thaw deterioration. Type M is high-strength mortar, which may be considered for load-bearing or severe freeze-thaw applications.

Type O is a low-strength mortar that is sometimes used for interior masonry of pointing. Special attention should be given when severe exposure conditions are expected. Type O mortar should not be used in saturated freezing conditions. Table 2.8 (adapted from ASTM C270) provided guidelines for selecting mortar unreinforced (plain) masonry [16].

Table 2.8: Guideline for the Selection of Masonry Mortars.

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">Building Segment</th><th colspan="2">Mortar Type</th></tr>
<tr><th>Recomended</th><th>Alternative</th></tr>
<tr><td rowspan="3">Exterior, above grade</td><td>Load-bearing wall</td><td>N</td><td>S or M</td></tr>
<tr><td>Non-load bearing wall</td><td>O</td><td>N or S</td></tr>
<tr><td>Parapet wall</td><td>N</td><td>S</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="3">Exterior, at below grade</td><td>Foundation wall, retaining wall</td><td rowspan="3">S</td><td rowspan="3">M or N</td></tr>
<tr><td>manholes, sewers, pavements</td></tr>
<tr><td>walks, and patios</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="2">Interior</td><td>Load-bearing wall</td><td>N</td><td>S or M</td></tr>
<tr><td>Non-load bearing wall</td><td>O</td><td>N</td></tr>
</table>

2.4.4.5 Related Items That Have an Effect on Properties

2.4.4.5.1 General

The factors influencing the successful conclusion of any project with the desired performance characteristics are the design, material, procedure and craftsmanship selected and used. The supervision, inspecting and testing necessary for compliance with requirements should be appropriate and predetermined [14].

2.4.4.5.2 Masonry Units

Masonry units are absorptive by nature, with the result that water is extracted from the mortar as soon as the masonry unit and the mortar come into contact. The amount of water removal and its consequences effect the strength of the mortar, the properties of the boundary between the mortar and the masonry units, and thus the strength, as well as other properties, of the masonry assemblage.

The suction exerted by the masonry unit is a very important external factor which affects the fresh mortar and initiates the development of bond. Masonry units vary widely in initial rate of absorption (suction). It is therefore necessary that the mortar chosen have properties that will provide compatibility with the properties of the masonry unit being used, as well as environmental conditions that exist during construction and the construction practices peculiar to the job.

The extraction of too much or too little of the available water in the mortar tends to reduce the bond between the masonry unit and the mortar.A loss of too much water from the mortar can be caused by low water retentivity mortar, high suction masonry units, or dry, windy conditions. When this occurs, the mortar is incapable of forming a complete bond when the next unit is placed. Where lowering the suction by prewetting the units is not proper or possible, the time lapse between spreading the mortar and laying of a masonry unit should be kept to a minimum. When a very low suction masonry unit is used, the unit tends to float and bond is difficult to accomplish. There is no available means of increasing the suction of a low suction masonry unit, and thus the time lapse between spreading the mortar and placing the unit may have to be increased.

Mortars having higher water retentivity are desirable for use in summer or with masonry units having high suction. Mortars having lower water retentivity are desirable for use in winter or with masonry units having low suction.

Shrinkage or swelling of the masonry unit or mortar once contact has been achieved affects the quality of the mortar joint. Protection should be provided to prevent excessive wetting, drying, heating or cooling, until the mortar has at least achieved final set.

Mortar bond is less to surfaces having an unbroken die skin or sanded finish than it is to roughened surfaces such as a wire cut or textured finish [14].

2.4.4.5.3 Construction Practice

Careful attention to good practice on the construction site is essential to achieve quality. Cementitious materials and aggregate should be protected from rain and ground moisture and air borne contaminants.

Proper batching procedures include use of a known volume container (such as a one cubic foot batching box) for measuring sand. When necessary, sand quantities should be adjusted to provide for bulking of the sand. Shovel measuring cannot be expected to produce mortar of consistent quality. Alternatively, a combination volumetric measure calibration of a mixer followed by full bag cementitious additions and shovel additions of sand to achieve the same volume of mortar in the mixer with subsequent batches, should prove adequate.

Good mixing results can be obtained where about three-fourths of the required water, one-half of the sand, and all of the cementitious materials are briefly mixed together. The balance of the sand is then charged and the remaining water added. The mixer should be charged to its full design capacity for each batch and completely emptied before charging the next batch.

Mixing time in a paddle mixer should usually be a minimum of 3 and a maximum of 5 min after the last mixing water has been added, to insure homogeneity and workability of the mortar. Overmixing results in changing the air content of the mortar. Worn paddles and rubber scrapers will greatly influence the mixing efficiency. Concern for quality suggests use of an automatic timer on the mixing machine. Mixing time should not be determined by the demand of the working force.

Weather conditions also should be considered when selecting mortar. During warm, dry, windy, summer weather, mortar must have a high water retentivity to minimize the effect of water lost by evaporation. In winter, a lower water retentivity has merit because it facilitates water loss from the mortar to the units prior to a freeze. To minimize the risk of reduced bond in cold weather, the masonry units being used as well as the surface on which the mortar is placed should both be brought to a temperature at least above 0°C before any work commences.

With very rapid drying under hot, dry and windy conditions, very light wetting of the in-place masonry, such as fog spray, can improve its quality. Curing of mortar by the addition of considerable water to the masonry assemblage, however, could prove to be more detrimental than curing of mortar by retention of water in the system from its construction. The addition of excess moisture might saturate the masonry, creating movements which decrease the adhesion between mortar and masonry unit [14].

2.4.4.5.4 Workmanship

Workmanship has a substantial effect on strength and extent of bond. The time lapse between spreading mortar and placing masonry units should be kept to a minimum because the flow will be reduced through suction of the unit on which it is first placed. This time lapse should normally not exceed one minute. If excessive time elapses before a unit is placed on the mortar, bond will be reduced. Elimination of deep furrows in horizontal bed joints and providing full head joints are essential. Any metal embedded in mortar should be completely surrounded by mortar.

Once the mortar between adjacent units has begun to stiffen, tapping or otherwise attempting to move masonry units is highly detrimental to bond and should be prohibited. The movement breaks the bond between the mortar and the masonry unit, and the mortar will not be sufficiently plastic to reestablish adherence to the masonry unit [14].

2.5 Plastering

2.5.1 General

Plastering is the process of covering rough walls and uneven surfaces in the construction of houses and other structures with a plastic material, called plaster, which is a mixture of lime or cement concrete and sand along with the required quantity of water [17].

Plasters may be defined as materials designed to provide a durable, flat, smooth, easily decorated finish to internal walls or ceilings. Traditionally they are based on lime and cement [18].

The composition of the plaster is typically almost same with the composition of the mortar. Only the purpose and application techniques are different.

2.5.2 Requirements for Good Plastering

1. It should adhere to the background and should remain adhered during all climatic changes.
2. It should be cheap and economical

3. It should be hard and durable
4. It should be possible to apply it during all weather conditions.
5. It should effectively check the entry or penetration of moisture from the surface
6. It should possess good workability [17].

2.5.3 Objective of Plastering

a. To provide an even, smooth, regular, clean and durable finished surface with improved appearance.
b. To conceal defective workmanship
c. To preserve and protect the surface
d. To provide a base for the decorative finish
e. To cover up the use of interior quality and porous materials of the masonry work [17].

2.5.4 Methods of Plastering

The plaster may be applied in one or more coats, but the thickness of a single coat should not exceed 12mm. In the case of inferior or cheaper type of construction, the plaster may usually be one coat. For ordinary type of construction, the plaster is usually applied in two coats, whereas for superior type of works it is applied in three coats. The final setting coat should not be applied until the previous coat is almost dry. The previous surface should be scratched or roughened before applying the next coat of plaster. In plastering, the plaster mix is either applied by throwing it with great force against the walls or by pressing it on the surface [17].

Maximum 3 types of coats may be used.

1.Render coat- levels the background.

2.Floating coat- produces flat surface of uniform suction

3.Finishing coat- provides a smooth, hard finish [18].

1.The first coat (rendering coat) of plaster is generally applied by dashing to make a rough surface (laying) for increase the plaster bond between first coat and second coat (main coat). It is sprinkled frequently with sufficient quantity of water and rubbed well by means of floats.

If a second coat, called floating coat, is to be applied, the surface of the first coat is left exposed to air for a period of 2 days to set but not to dry. After this period, the surface of the first coat is swept clear of any dust or loose particles, sprinkled with water and well beaten with thin strips of bamboo or cane. The surface of the first coat is kept wet till the second coat is applied.

2. Second coat or floating coat is applied after preparing the surface of the first coat as mentioned above. The second coat is spread out uniformly with trowels. It is pressed and rubbed with a wooden straight edge, to obtain the desired surface. It is finally finished by slightly sprinkling water over the plastered surface and rubbing it with the floats. The thickness of the second coat is usually between 6 an 9 mm.

3. Third coat or final coat or finishing coat is applied after 5 days of the second coat. This coat consists of a cream of white or fat lime (called neeru or plaster's putty) and fine white sand in the ratio of 1:2 laid in thickness of 3mm with straight plane and is rubbed with a straight edge. The surface is well rubbed with a wooden float and then finally finished with trowel to obtain the desired surface. A polishing Stone is used to obtain a fine polished surface [17].

2.5.5 Types of Plastering

2.5.5.1 Cement Plastering

Cement plastering is an ideal plastering for external rendering. It is specially suited for damp conditions such as bathrooms, reservoirs, water tanks, floors, copings, etc.where non-absorbent surface are desired. Cement plaster is usually applied in a single coat. However, in certain cases when the thickness of the plaster is more than 15mm or it is desired to have a finer finish, the plaster is applied in two coats. Cement sand mixtures are quite rapid hardening. The risk of surface cracking is increased with increasing cement content in the mixtures [19].

A. First coat or rough coat: Usually, the average thickness of the first coat of plaster is 12mm on brick masonry or ashlar masonry and 23 mm on ruble masonry. In the case of concrete masonry, this thickness varies from 9 to 15 mm depending upon the nature of work. For the first coat, cement plaster with mix proportions as 1:3 or4 (1 cement:3 or 4 sand) is generally used. The first coat of plaster is placed between the spaces or bays formed by the screeds on the wall surface. This plaster is applied with a mason's trowel. The surface is then levelled by means of flat wooden floats and wooden straight edges and finally finished by polishing with trowel. If a second coat or fine coat is to be applied, the surface of the first coat is not polished, but roughened with a scratching tool to form a key to the second coat of plaster.

B. Second Coat or Fine Coat: Before applying the second, the first coat is left to set for at least 7 days and is roughened to form a proper key with the second coat. The second coat, consisting of pure portland cement mixed with sufficient quantity of water, is applied after 6 hours. This second coat is laid in a thin layer of 3 mm maximum thickness over the rough and moist surface of the first coat. Finally, this coat is well trowelled and rubbed smooth. Each coat should be kept damp continuously by curing for at least 5-10 days [17].

Table 2.9: Plaster in Three Coats with Cement Mortar.

Type of Coat	Name of Coating	Thickness	Remarks
First Coat	Rendering Coat	9-10 mm	This is left for a period of 3-4 days to harden. Its surface is kept rough.
Second Coat	Floating Coat	6-9 mm	The purpose of this coat of plaster is to bring the work to an even surface
Third Coat	Setting coat or finishing coat	3 mm	This coat is similar to the second coat of a two coat plaster

2.5.5.2 Cement-Lime- Sand Plastering

This type of plaster is possesses higher value of workable and applicability. The rate of hardening increases with the increasing of cement content in the mix. However the rate of workability increases with th increasing of lime content in the mix. Moreover the rate of hardening reduced by increasing lime content in the mix [19]. This type of plaster generally applied as a second coat (floasting coat) in plastering process. For the second coat the mix proportion as 1:2:8 (1:cement, 2:lime, 8:sand) by volume proprotion is generally used.

2.5.5.3 Lime-Sand Plastering

The main properties of this plaster is higher workable. Moreover during drying process lime sand plastering is assist to reduce the risk of shrinkage cracking [19].

2.5.5.4 Gypsum Plaster

Main advantages of gypsum plasters are:

-Their setting time can be controlled.

-Time delay between successive coats may be very small.

-Various surface textures and surface hardness can be obtained.

-If plastering technique is correct they will not shrink like cement based plasters.

-Excellent fire-resistance. Contains 21% water of crystallisation which absorbs heat and minimises the rate of temperature rise in behind the plaster.

However Gypsum plasters are not suitable for exterior uses except very effective permanent protection is provided [18].

Essential gypsum plasters are classified into four groups named as A,B,C,D

2.5.5.4.1 Class A-Hemihydrate ($CaSO_4$ .1/2 H_2O: Plaster of Paris)

Produced by heating to a temperature not in excess of 200^{o}C. Sets within 5-10 minutes of adding water, which is far too rapid to permit use in ordinary trowel trades. It is useful for decorative plasterwork and for as a repair layer [18]. It is impossible to use without lime in interior plastering [19].

2.5.5.4.2 Class B- Retarded hemihydrates ($CaSO_4$ .1/2 H_2O)

Produced by adding set retarder (keratin) to Class A plaster. The amount of retarder can be changed. Normally designed to be used with sand in ratios of up to 3:1 sand : plaster. Setting times are in the range of 2-3 hours. Addition of hydrated lime accelerates the set (1-1.5 hours) of plaster. This is normally 25% by weight of hydrated lime. Premixed plasters containing lightweight aggregates are now widely used. Board finish plasters are in this class [18].

2.5.5.4.3 Class C-Anhydrate

Obtained by heating the raw material to a higher temperature than class B plasters. Slow setting is accelerated by adding alum. Initial set is fast and final set is slow. Used as finishing coat on a sand/cement backing [18].

2.5.5.4.4 Class D- Anhydrate (Keens's cement)

This is burnt harder than class C. There is higher proportion of anhydrate. The product has very high strength with superior smoothness and hardness. Applied on squash court walls where a durable finish is required. Ideal base for gloss finish [18].

2.5.6 Lightweight Aggregates in Plasters

Low-density aggregates (expanded perlite and pumice- produced from siliceous volcanic glass and exfoliated vermiculite-produced from mica) are a most important ingredient of modern plasters, which are now almost always premixed.

Some advantages of this plasters are following:

- Transporting and handling costs of the plaster are reduced.
- The low-density fresh material requires less effort to mix and apply and can be used in thicker coats.
- The thermal insulation of walls or ceilings is improved and the internal surface temperature increased.
- Fire performance of structures is improved [18].

2.6 Thermal Properties of Masonry Systems

2.6.1 General

The recurrence of energy crises, coupled with increased public aeareness and government action, have encouraged the development of building codes that include energy-conservation requirements. To reduce the use of nonrecoverable energy sources, almost all states and counrties have now adopted energy-conservation building codes and standards that apply to design and construction of buildings. The design of energy-conserving buildings now requires an expanded understanding of the thermal properties of the building envelope and the materials that comprise the envelope system.

Due to its inherent functionality and availability of raw materials used in its production, concrete and masonry are the world's most widely used building materials. Many civilizations have built structures with concrete and masonry walls that provide uniform and comfortable indoor temperatures despite all types of climatic conditions.

Housing systems have been developed featuring efficient load-bearing concrete masonry wall systems that provide resistance to weather, temperature changes, fire, and noise. Many of these wall systems are made with lightweight concrete where the wall thickness is often determined by thermal characteristic rather than structural requirements [20].

2.6.2 Thermal Conductivity of Concrete

Thermal conductivity is a specific property of a gas, liquid, or solid. The coefficient of thermal conductivity 'λ' is a measure of the rate at which heat (energy) passes perpendicularly through a unit area of homogeneous material of unit thickness for a temperature difference of one degree; 'λ' is expressed as 'W/mK'

The coefficient of thermal conductivity for concrete 'λ' is dependent on the aggregate types used in the concrete mixture [20].

2.6.3 Thermal Conductivity of Concrete Used in Concrete Masonry Units

Concrete Masonry Units (CMU) usually consist of approximately 65 to 70% aggregates by volume. The remaining volume consists of voids between aggregate particles, entrained air, and cement paste. The typical air-void content of concrete used to make lightweight CMUs, for example, has been found to be 10 to 15% by volume. Expressed as a percentage of the cement paste, void volumes are approximately 30 to 45%. For a typical lightweight CMU having a net w/c of 0.6 and an average cement-paste air-void content of 40%, the thermal conductivity would be in range of 0.22 to 0.26 W/mK. Such values are typical lightweight aggregate, concrete (void-free) because the air spaces found in the zero slump CMU lightweight concrete provide additional heat flow resistance, thus lowering the conductivity.

Additionally at the same concrete density, a coarse-lightweight aggregate gradation provides a concrete with a higher thermal conductivity value than a fine-lightweight aggregate gradation concrete due to the differences in aggregate (coarse fraction) and paste (fine gradation) volume fractions [20].

2.6.4 Thermal Resistance of Concrete Masonry Units

Thermal resistance of CMUs is affected by many variables, including unit shape and size, concrete density, insulation types, aggregate types, aggregate gradation, aggregate minerology, cementitious binder, and moisture content. It simply is not feasible to test all of the possible variations [20].

2.6.5 Thermal Mass of Concrete Masonry Systems

The terms thermal mass or thermal inertia describe the absorption and storage of significant amounts of heat in a building or in walls of a building. Concrete and masonry heat and cool slowly and stay warm (or cool) longer than many other building materials. This thermal mass effect delays and reduces heat transfer through a concrete or masonry wall, resulting in a reduction in total heat loss or gain through the building envelope. The reduced heat transfer through concrete or masonry is not a heat loss but rather indicates that some of the heat is stored in the element an later released back into the room. Outdoor daily temperature cycles have a lesser effect on the temperature inside a thermally massive building because massive materials reduce heat transfer and moderate the indoor temperature [20].

2.6.5.1 Factors affecting the Thermal Mass Effect

Many inter-related factors contribute to the actual energy savings from the thermal mass of a building. These include the amount and placement of concrete or masonry materials, insulating, and Windows; the building orientation; and the climate. The relative importance of each of these factors depends on the building use and design [20].

2.6.5.1.1 Thermal Diffusivity

Thermal diffusivity indicates how quickly a material changes temperature. A high thermal diffusivity indicates that heat transfer through a material will be fast and the amount of storage will be small. Materials with a high thermal diffusivity respond quickly to changes in temperature. Low thermal diffusivity means a slower rate of heat transfer and a larger amount of heat storage. Materials with low thermal diffusivity respond slowly to an imposed temperature difference. Materials with low thermal diffusivities, such as concrete and masonry, are effective thermal mass elements in a building [20].

2.6.5.1.2 Heat Capacity

Heat capacity is another indicator of thermal mass, one that is often used in energy codes. Concrete and masonry, because they absorb heat slowly, will generally have higher heat capacities than other materials. Heat capacity is defined as the amount of heat necessary to raise the temperature of a given mass one degree. More simply, it is the product of a mass and its specific heat. In concrete or concrete masonry, the heat capacity of walls is determined by multiplying the wall mass per area (kg/m^2) by the specific heat (J / [kg.K]) of the wall material [20].

2.6.5.1.3 Insulation

The physical location of wall insulation relative to wall mass also significantly affects thermal performance. In concrete masonry walls, insulation can be placed on the interior of the wall, integral with the masonry, or on the exterior and is most effective when placed on the exterior. For maximum benefits from thermal mass, the mass should be in direct contact with the interior conditioned air. Because insulation on the interior of the mass thermally isolates the mass from the conditioned space, exterior insulation strategies are usually recommended. For example, rigid board insulation applied on the wall exterior, with a finish applied over the insulation, is generally more energy efficient than furring out the interior of a mass wall and installing batt insulation. Integral insulation strategies include insulating the cores of a masonry unit, using an insulated concrete sandwich panel, or insulating the cavity of a double-wythe masonry wall. In these cases, mass is on both sides of the insulation. Integral insulation allows greather thermal mass benefits than interior insulation but not as much as exterior insulation [20].

2.6.5.1.4 Building Design

Building design and use can impact thermal mass because different buildings use energy in different ways. In low-rise residential construction, heathing and cooling are influenced by the thermal performance of the building envelope. These buildings are said to have skin dominated thermal loads, and the effects of thermal mass for low-rise residential buildings are influenced primarly by climate and wall construction.

On the other hand, the thermal mass of commercial and high-rise residential buildings is significantly affected by internal heat gains in addition to the climate and wall construction. Large internal heat gains from lighting, equipment, occupants, and solar transmission through Windows create a greather need for thermal mass to absorb heat and delay heat flow. The benefits of thermal mass in commercial buildings are generally greather than for low-rise residential buildings [20].

Chapter 3

EXPERIMENTAL STUDY

3.1 Introduction

In this study, mortar and plaster made of limestone and pumice aggregates were studied for physical and mechanical properties. Physical properties of pumice and limestone aggregate namely; particle size distribution, bulk density, specific gravity and water absorption capacities were determined. Besides geometrical analysis for pumice block masonry units were done. Mix proportioning (by weight) for mortar and plaster made of limestone and pumice aggregate were determined and explained in this chapter. Various tests were performed, and the experimental studies were categorized in 3 main groups which were fresh mix properties, hardened mix properties (physical) and mechanical properties of hardened mixes. Experimental test procedures as well as related photos and figures are explained and shown in detail. Tests for fresh mix properties namely, consistency of fresh mortar (flow value), time of setting and fresh unit weight were performed seperately for traditional and pumice mortars by means of first coat, second coat and joint mortar. As for mechanical properties namely, compressive strength, flexural strength and pulse velocity were determined. As for hardened properties (physical) namely, capillary water absorption, water absorption, hardened unit weight and drying shrinkage were determined seperately for traditional and pumice mortars by means of first coat, second coat and joint mortar in this investigation.

Afterwards, the coefficient of thermal conductivity of different wall systems in terms of different mortar/plaster as well as block types were determined and compared among themself and with wall made of clay brick of size 100 x 200 x 300 mm. Three different size of pumice-blocks were used and totally seven different wall systems were created in order to compare thermal conductivity coefficients.

3.2 Materials Used

3.2.1 Pumice Aggregate

In this investigation, pumice aggregates were provided by Escon Ltd in N.Cyprus. This company imports pumice aggregates from Nevşehir region (Turkey) in order to manufacture pumice-block masonry units for N.Cyprus construction industry. The chemical composition of pumice used in this investigation is shown in Table 3.1 .

Table 3.1: Chemical Composition of Nevşehir Pumice

Chemical Composition	Nevşehir Pumice
SiO_2	74%
Al_2O_3	13%
Fe_2O_3	1.40%
FeO	0.00%
CaO	1.17%
Na_2O	3.70%
K_2O	4.10%
MgO	0.07%

As can be seen in above table, SiO_2 content is quite high and this shows that Nevşehir pumice is asidic type of pumice. As explained in chapter 2 , asidic type of pumice is desired especially in construction sector depends on its chemical composition. Moreover it is clear that Nevşehir pumice is higly pozzolanic material and it provides serious advantages for durability and strenght gain of the mix.

Pumice aggregates used are shown in Photo 3.1

Photo 3.1: Pumice Aggregates Provided by Escon Ltd.

According to TS EN 998-2, the maximum size of aggregate must be 2 mm in order to be used in mortar and plaster. Therefore, the aggregates were sieved from 2 mm sieve and particles passing the sieve were used in this investigation. To increase the rate of sieving, bigger size of sieve were formed and used as shown in Figure 3.2 and 3.3 .

Photo 3.2: Sieve Used to Obtain Required Size of Aggregates.

Photo 3.3: Sieving of Pumice Aggregates in Laboratory from 2 mm Sieve.

The sieved pumice aggregates (≤ 2mm) are shown in Photo 3.4

Photo 3.4: Sieved Pumice Aggregates (size ≤ 2 mm)

Particle size distribution (grading) of pumice aggregate is shown in Table 3.2 and Figure 3.1 below.

Table 3.2: Sieve Analysis of pumice aggregate.

Sieve Size (mm)	**Mass Retained (gr)**	**Per. Ret**	**Cum. Ret (%)**	**Cum.Passing (%)**
2.36	0.00	0.00	0.00	100.00
1.18	224.00	31.20	31.19	68.81
0.6	153.00	21.31	52.50	47.50
0.3	62.00	8.64	61.13	38.87
0.15	47.00	6.55	67.68	32.32
Pan	232.00	32.31	99.99	0.01

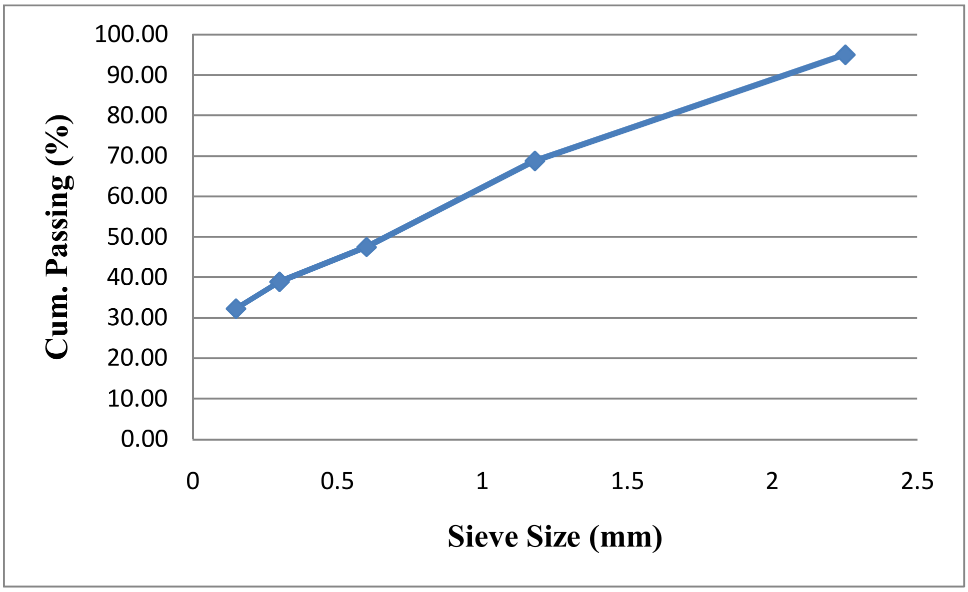


Figure 3.1: Grading Curve of Pumice Aggregate

There is no any standard grading such as upper and lower limit for making mortar. Only critical standard as mentioned before is the maximum size of aggregate. According to TS EN 998-2, the maximum size of aggregate must be in 2 mm to use for production of mortar. Therefore the particle sizes of pumice aggregates are satisfied according to the standard used.

3.2.2 Limestone Aggregates

Limestone aggregates are provided from Beşparmak Mountain in Cyprus. Cyprus is very rich in terms of limestone sources. Especially all the Beşparmak mountains contains limestone in Cyprus. Limestone is used as aggregate in concrete and mortar in construction sector of Cyprus.

Limestones are sedimentary rock and contains at least 50 percent Calcium Carbonate ($CaCO_3$). Limestone aggregates used in this investigation are shown in Photo 3.5 .

Photo 3.5: Limestone Aggregate (size ≤ 2 mm)

Particle size distribution (grading) of limestone aggregate are shown in Table 3.3 and Figure 3.2

Table 3.3: Sieve Analysis of Limestone Aggregate

Sieve Size (mm)	Mass Retained (gr)	Per. Ret	Cum. Ret (%)	Cum. Passing (%)
2.36	0.00	0.00	0.00	100.00
1.18	387.00	30.71	30.71	69.29
0.6	283.00	22.46	53.17	46.83
0.3	191.00	15.16	68.33	31.67
0.15	116.00	9.21	77.54	22.46
Pan	284.00	22.54	100.00	0.00

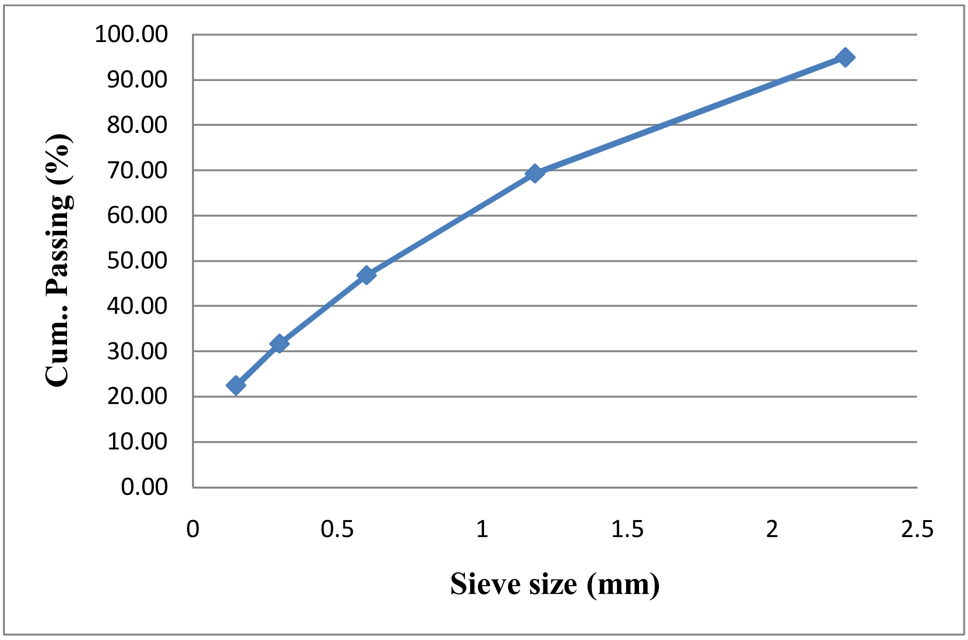


Figure 3.2: Grading Curve of Limestone Aggregate.

As explained before, there is no standard specifying upper and lower limits for aggregates used in mortar. As mentioned before the maximum size of aggregate must be 2 mm in order to be used in the production of mortar. Therefore the particle sizes of limestone aggregates are satisfied the related standard used in this investigation. Moreover it is clear that the particle size distribution of limestone aggregates are almost same compared with pumice aggregates used in this investigation.

3.2.2.1 Comparasion of Bulk Densities , Specific Gravities and Percentage of Absorption of Pumice Aggregates and Limestone Aggregates

3.2.2.1.1 Bulk Density

The uncompacted bulk densities (loose state) and compacted bulk densities (denser state) of pumice aggregates and limestone aggregates used in this investigation are shown in table 3.4 below.

Table 3.4: Bulk Densities of Pumice and Limestone Aggregates

Type of Aggregate	Compacted Bulk Density (kg/m^3)	Uncompacted Bulk Density (kg/m^3)
Pumice	860	808
Limestone	1990	1777

As shown in Table 3.4, the bulk densities of pumice aggregates are quite low compared with limestone aggregates due to characteristic properties of pumice aggregates. As expalined before that pumice aggregates contains up to 80% air voids. Therefore pumice aggregate possesses very high value of porosities. As can be seen in above table, the bulk densitites of pumice aggregates are 2.5 times lower compared to limestone aggregates in both cases.

3.2.2.1.2 Specific Gravity and Percentage of Absorption

Specific gravity is the ratio of the weight of a substance to the weight of an equal volume of water. Therefore it is unitless. The specific gravities and percentage of absorption of pumice aggregates and limestone aggregates used in this investigation are shown in Table 3.5 as follows:

Table 3.5: Specific Gravities and Percentage of Absorption of Pumice and Limestone Aggregates

Type	Bulk Specific Gravity	Bulk Specific Gravity (SSD)	Apparent Specific Gravity (SSD)	(%) of Absorption
Pumice	1.151	1.621	2.173	40.84
Limestone	2.35	2.43	2.55	3.36

As shown in Table 3.5, the specific gravities (Bulk Specific Gravity, Bulk Specific Gravity (SSD) and Apparent Specific Gravity) of pumice aggregates are quite lower compared with limestone aggregates due to characteristic properties of aggregates. It is clear that specific gravities of pumice aggregates are around 2 times (especially Bulk Specific Gravity) lower than the specific gravities of limestone aggregates.

Moreover the water absorption capacity of pumice aggregate are very high compared with the water absorption capacity of limestone aggregates. This is directly due to the structure of pumice aggregate. As can be undersood from the result pumice is like a sponge due to excessive air voids. It is clear that the percentage of water absorption of pumice aggregate is around 14 times much higher compared with limestone aggregate.

3.2.3 Cement

The cement used in all investigation was an Portland Pozzolanic Cement(class 32.5) meeting all the requirements of ASTM C-150. The chemical composition of cement is as shown in Table 3.6.

Table 3.6: Chemical Composition of Cement Used in this Investigation

Chemical Composition	**Percentage (%)**
CaO	38
MgO	4
SO_3	3
SiO_2	46.8
AL_2O_3	5.3
Na_2O	0.15
Fe_2O_3	3.46
LOI	3

Physical and Mechanical Properties of Cement are shown in Table 3.7.

Table 3.7: Physical and Mechanical Properties of Cement Used in this Investigation.

Fineness (m^2/kg)	451
Initial Setting (Min)	90
Final Setting (Min)	135
Specific Gravity	3.28
Compressive Strenght (Mpa) 3 Days	18.3
Compressive Strenght (Mpa)28 Days	35.7

3.2.4 Lime

The lime used in all investigation was a slaked powder lime.

Lime is a general term for calcium-containing inorganic materials, in which carbonates, oxides and hydroxides predominate. Strictly speaking, lime is calcium oxide or calcium hydroxide. Calcium hydroxide, traditionally called slaked lime, hydrated lime, slack lime, or pickling lime, is a chemical compound with the chemical formula $Ca(OH)_2$. It is a colourless crystal or white powder, and is obtained when calcium oxide (called *lime* or *quicklime*) is mixed, or "slaked" with water.

3.2.5 Water

The water used in all investigation was a drinkable water available in Materials of Construction Laboratory at E.M.U .

3.2.6 Pumice Blocks

The Pumice-blocks used in this investigation was provided by Escon Ltd. Escon Ltd. is one of the best and most popular construction material company especially in respect to pumice block productions in N.Cyprus. Moreover this investigation is sponsored by Escon Ltd.

Three different sizes of pumice-blocks (hollow) meeting all the requirements of TS 2823 were used in this investigation.

3.2.6.1 Geometrical Analysis of Pumice-Blocks

The symbolic dimensions used in pumice block design are shown in Figure 3.3 .

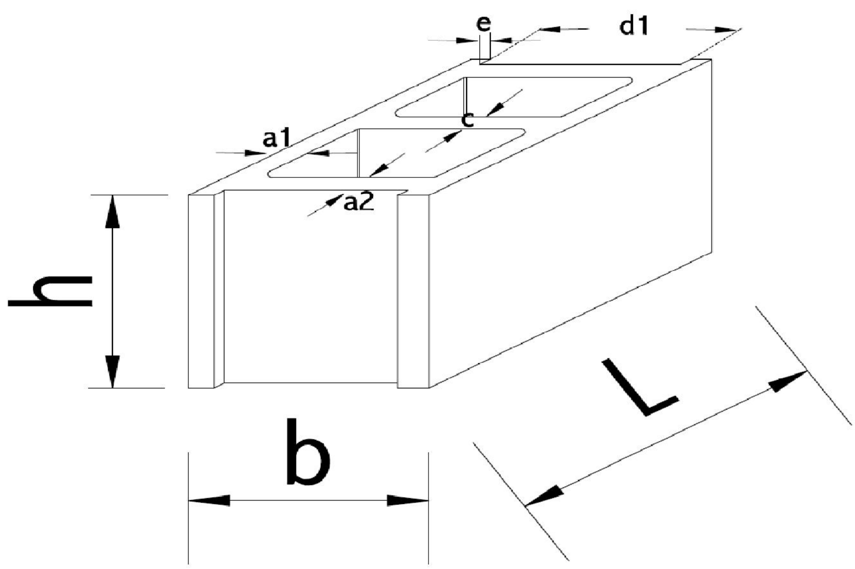


Figure 3.3: Symbolic Dimensions of Pumice Block

Where

L: Length (mm)

b: Thickness (mm)

h: Height (mm)

a1: Longitudinal exterior wall thickness (mm)

c: Interior wall thickness (mm)

d1: Breast mortar length (mm)

e: Breast mortar thickness (mm)

a2: Crosswise exterior wall thickness (mm)

The nominal dimensions of pumice blocks used in this investigation are given in Table 3.8 below.

Table 3.8: Nominal Dimensions of Pumice-Blocks used in This Investigation.

TYPE NO:	DIMENSIONS (mm):	THICKNESS (mm):
1	150 X 390 X 185	150
2	190 X 390 X 185	190
3	250 X 390 X 185	250

3.2.6.1.1 Type 1 Pumice Block

Type 1 pumice block are shown in Photo 3.6.

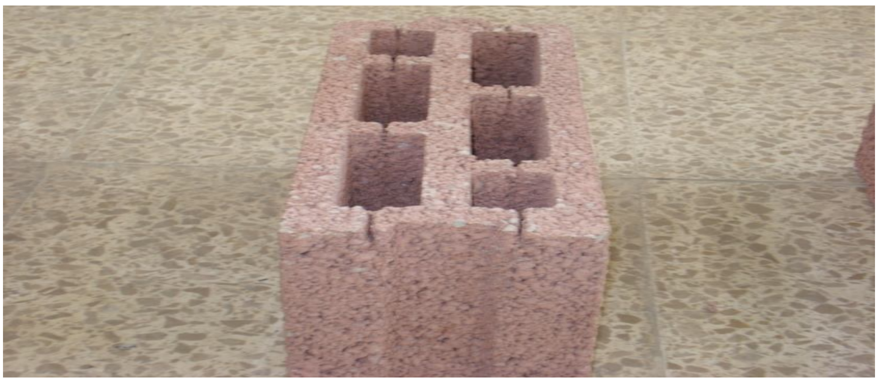


Photo3.6: Type 1 Pumice Block with Dimensions 150 x 390 x 190 mm

As can be seen in photo 3.6 type 1 pumice block is a two file hollow type of pumice block.

The symbolic top view of type 1 pumice block used in this investigation are shown in Figure 3.4

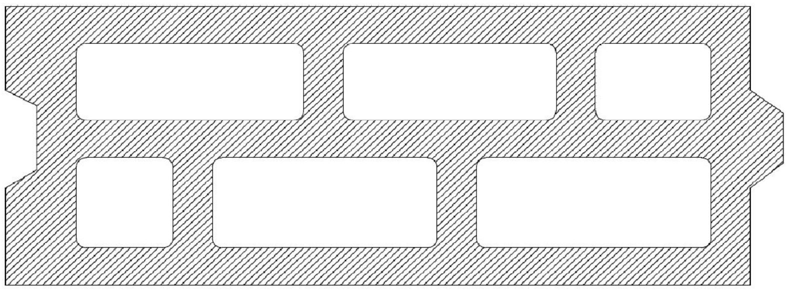


Figure 3.4: Type 1 Pumic block (2 file hollow) with Dimensions 150 x 390 x 185 mm

The design dimensions of type 1 pumice-blocks are given in Table 3.9

Table 3.9: Design Dimensions of Type 1 Pumice Block (2 file hollow)

Type 1: 150 x 390 x 185 mm							
L (mm)	**b (mm)**	**h (mm)**	**a1 (mm)**	**c (mm)**	**d1 (mm)**	**e (mm)**	**a2 (mm)**
390	150	185	25	20	45	15	20

The surface areas , proportions of solid surface area and unit weight are given in Table 3.10

Table 3.10: Surface area, Proportion of Solid Surface Area and Unit Weight of Type 1 Pumice Block

Surface Area (mm^2)	58500
Empty Surface Area (mm^2)	20325
Solid Surface Area (mm^2)	38175
Proportion of Solid Surface Area (%)	65.25
Unit Weight (kg/m^3)	740

3.2.6.1.2 Type 2 Pumice-Block

Type 2 pumice block are shown in Photo 3.7

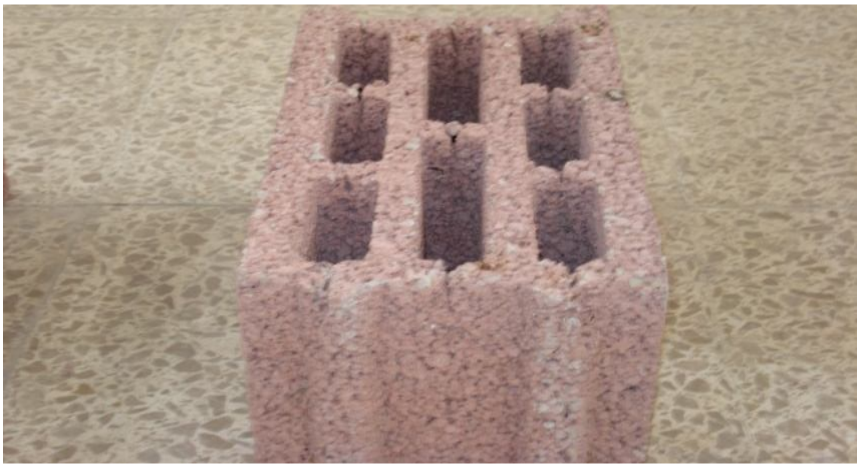


Photo 3.7: Type 2 Pumice Block with Dimensions 190 x 390 x 185 mm

As can be seen in Photo3.7 type 2 pumice block is a three file hollow type of pumice block.

The symbolic top view of type 2 pumice block used in this investigation are shown in Figure 3.5

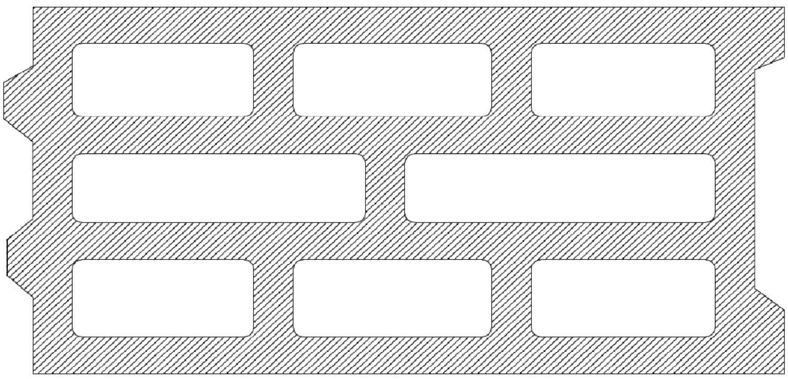


Figure 3.5: Symbolic Top View of Type 2 Pumice Block (3 File Hollow) of Dimensions 190 x 390 x 185 mm

The design dimensions of type 2 pumice-block are given in Table 3.11.

Table 3.11: Design Dimensions of Type 2 Pumice Block (3 File Hollow)

Type 2: 190 x 390 x 185 mm							
L (mm)	**b (mm)**	**h (mm)**	**a1 (mm)**	**c (mm)**	**d1 (mm)**	**e (mm)**	**a2 (mm)**
390	190	185	25	20	130	20	25

The surface areas, proportions of solid surface area and unit weight are given in Table 3.12.

Table 3.12: Surface Areas, Proportions of Solid Surface Area and Unit Weight of Type 2 Pumice Block

Surface Area (mm^2)	74100
Empty Surface Area (mm^2)	27800
Solid Surface Area (mm^2)	50300
Proportion of Solid Surface Area (%)	62
Unit Weight (kg/m^3)	712

3.2.6.1.3 Type 3 Pumice Block

Type 3 pumice block are shown in Photo 3.8

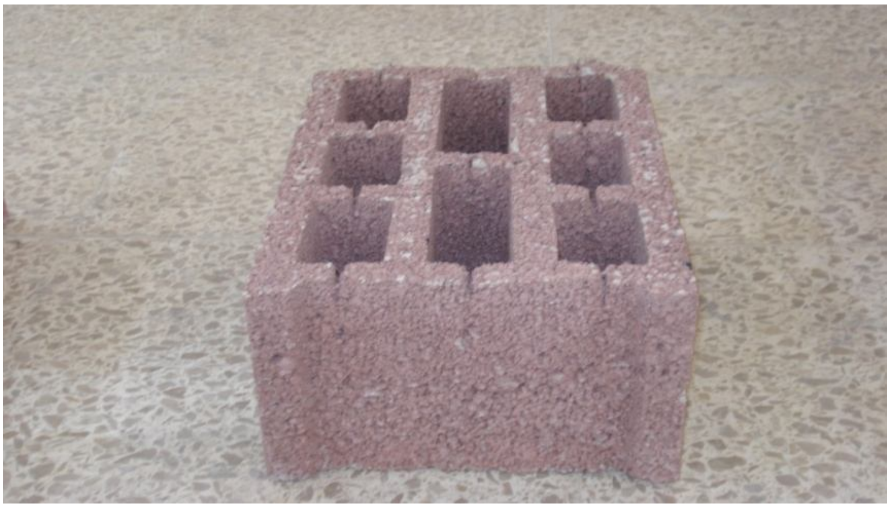


Photo 3.8: Type 3 Pumice block with Dimensions 250 x 390 x 185 mm

As can be seen in Photo 3.8. type 3 pumice block is a three file hollow type of pumice block.

The symbolic top view of type 3 pumice block used in this investigation are shown in Figure 3.6.

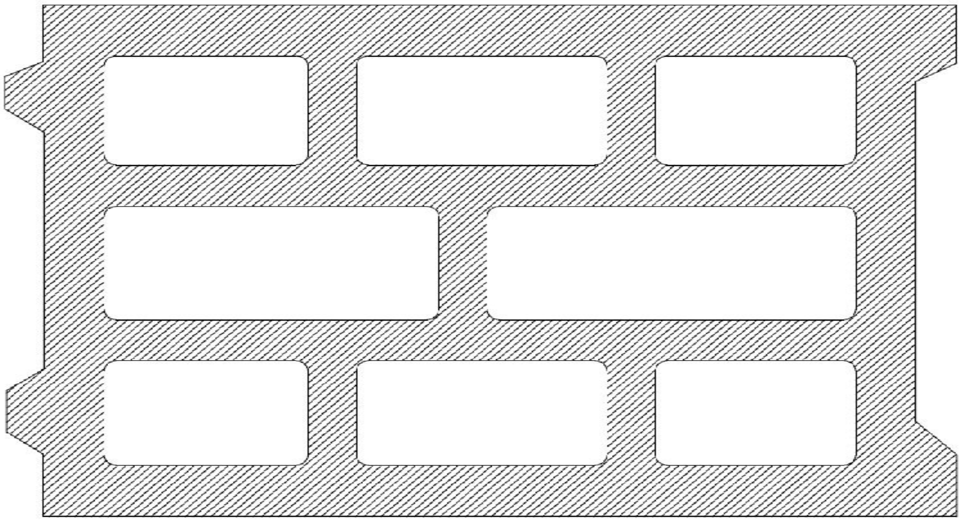


Figure 3.6: Symbolic Top View of Type 3 (3 File Hollow) in Dimensions 250 x 390 x 185 mm

The design dimensions of type3 pumice-block are given in Table 3.13.

Table 3.13: Design dimensions of Type 3 Pumice Block (3 file hollow)

Type 3 : 250 x 390 x 185 mm							
L (mm)	**b (mm)**	**h (mm)**	**a1 (mm)**	**c (mm)**	**d1 (mm)**	**e (mm)**	**a2 (mm)**
390	250	185	25	25	190	20	25

The surface areas, proportions of solid surface area and unit weight are shown in Table 3.14.

Table 3.14: Surface Areas , Proportion of Solid Surface Area and Unit Weight of Type 3 Pumice Block.

Surface Area (mm^2)	97500
Empty Surface Area (mm^2)	40500
Solid Surface Area (mm^2)	57000
Proportion of Solid Surface Area (%)	58.5
Unit Weight (kg/m^3)	675

3.3 Mix Proportioning For Mortar and Plaster

3.3.1 General

In this investigation, mainly two types of mortar and plaster were produced by using different types of aggregates. These two parameters namely; mortar and plaster were developed by using pumice as aggregates instead of limestone aggregate.

Principally two different types of mortar and plaster were produced in terms of different aggregate types namely; lightweight mortar/plaster made of pumice aggregate and traditional mortar/plaster made of limestone aggregate. As it is well known that plaster are applied as a three coats in wall construction namely; first coat, second coat and third coat. Nowadays, ready-mixed plasters are used as third coat in construction sector of N.Cyprus. Ready-mixed plasters do not contain aggregates. In this investigation ready-mixed plaster was applied on the walls as third coat by taking into consideration of construction sector of N.Cyprus.

Consequently the plaster produced in this investigation were typically as first coat and second coat by using different aggregate types and two different joint mortars made of pumice and limestone aggregate.

3.3.2 Proportions of Materials

In construction sector of N.Cyprus, the mix proportions of materials used for mortar and plaster are done based on volumetric batching. Almost all contractors, civil engineers and arthitects are taken up reference of the technical specification for construction work prepared by 'Union of the Chambers of Cyprus Turkish Engineers and Architects (KTMMOB)' . Mix proportions by volume of materials for mortar and plaster indicated by specifications of KTMMOB are shown in Table 3.15 .

Table 3.15: Mix Proportions by Volume Specified by KTMMOB [22].

	Mix Proportions by Volume		
Type	**Cement**	**Lime**	**Sand≤ 2mm**
Joint Mortar	1	2	8
1. Coat	1	0	3
2. Coat	1	2	8

As can be seen in above Table 3.15 the mix proportions and compositions of joint mortar and second coat of plaster are same. Therefore these mix proportions (Table 3.15) has been taken into consideration in this investigation.

However, the mix proportions indicated are by volume. Particularly for laboratory mixed batches, determining the amount of materials by weight would become more consistent. Therefore in this investigation mix proportions by volume were converted to proportions by weight in order to establish the amount of materials used in the mixes. This process was performed according to ASTM C-270.

ASTM C-270 states that; convert proportions by volume to proportions by weight, using a batch factor calculated by Equation 3.1 and Equation 3.2 below:

Batch Factor = 1440 / (80 times total sand volume proportion)………………….(3.1)

Determine the weight of material as follows:

Material Weight = Material Volume Proportion x Bulk Density x Batch Factor…………………………………………………………………………...(3.2)

As can be indicated in above equations when converting volume proportions to batch weight, the bulk densities of materials are used. Bulk densities of materials used in the mixes are shown in Table 3.16 as follows:

Table 3.16: Bulk Densities of Materials Used in Mixes

Type of Materials	**Bulk Density (kg/m^3)**
Pumice Aggregate	808
Limestone Aggregate	1777
Cement	1200
Lime	600

According to above procedure, mix proportions by volume were converted to proportions by weight and presented in Table 3.17 and 3.18 as follows:

Table 3.17: Mix Proportions by Weight for Traditional (Limestone) Plaster and Mortar

Traditional (Limestone) Plaster and Joint Mortar				
Type	**Cement**	**Lime**	**Limestone**	**Water**
1.Coat	1	0	4.44	1.12
2. Coat	1	1	11.8	2.65
Joint Mortar	1	1	11.8	2.65

Table 3.18: Mix Proportions by Weight for Pumice Plaster and Mortar

Pumice Plaster and Joint Mortar				
Type	**Cement**	**Lime**	**Pumice**	**Water**
1. Coat	1	0	2.02	1.4
2. Coat	1	1	5.38	3.2
Joint Mortar	1	1	5.38	3.2

Amount of water were determined by taken into consideration of the consistency of fresh mortar. Consistency of fresh mortar were analyzed according to TS EN 1015-3. Test procedure is explained in detail in the next stage of this chapter.

It is clear that amount of water in pumice mortar and plaster are much more compared with mortar and plaster (traditional) made of limestone aggregate, due to higher capacity of water absorption of pumice aggregate. In this investigation, the consistency of both pumice and traditional mortars except first coat were tried to kept in the same range. The consistency of first coat both pumice and traditional is more fluid compared with second coat and joint mortars. First coat of plaster also called rough rendering due to its application technique. For this reason consistency of first coat is more fluid compared with other mortars. Test procedure of consistency of mortars (TS EN 1015-3) are explained in the next stage of this chapter and the results obtained are explained in detail in chapter 4.

3.4 Experiments

3.4.1 Mixing of Materials for Test Specimen

Materials were mixed in all invesitigations by a mortar mixer in order to prepare fresh mortar for test specimen (Photo 3.9).

Photo 3.9: Mortar was Mixed by Mortar Mixer for Prepare Test Specimens.

3.4.2 Determination of Fresh Mix Properties

In this investigation, consistence of fresh mortar, time of setting of mortar and fresh unit weight of mortar were determined by means of determination of fresh mix properties of mortars.

3.4.2.1 Determination of Consistence of Fresh Mortar (By Flow Table)

Consistency of fresh mortar were analyzed by using flow table according to TS EN 1015-3. The purpose of this test is for the determination the flow value of fresh mortar over time or in other words to identify the workability limit of the fresh mortar.

First of all, the fresh mortar is placed inside the metal mould located on the flow table. Then the metal mould is taken away and the flow table is dropped five times within three seconds (Photo 3.10). Afterwards the flow diameter is measured by use of compass (Photo 3.11) and (figure 3.7). The diameter of the mould is 100 mm therefore the flow diameter of fresh mortar will be bigger than 100 mm. The workability limit of fresh mortar is 130 mm. This means that workability is lost when the flow diameter reduced under 130 mm. Flow diameter of fresh mortar will be decreased over time due to hydration process and setting time. Flow diameter of fresh mortar is measured in one hour interval during 6 hours. Throughout this test, the fresh mortar samples must keep in a pot . Finally the results obtained in this test is shown in a chart with time versus flow diamater and analysis of results are done.

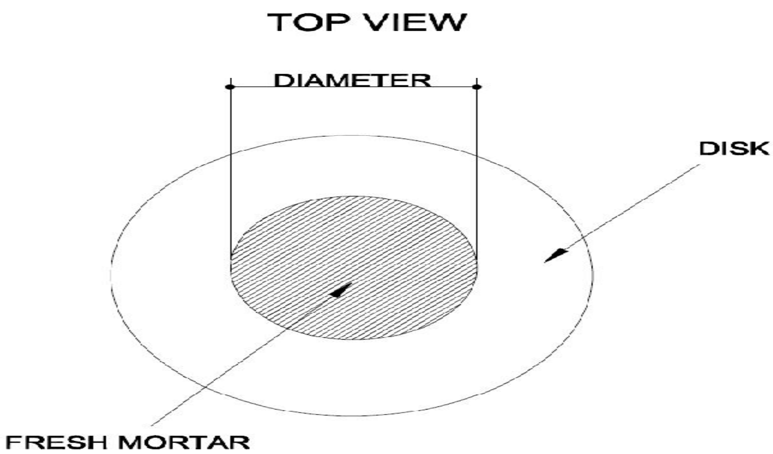


Figure 3.7: Symbolic Top View of Type 3 (3 File Hollow) in Dimensions

Photo 3.10: Determination of Consistency of Fresh Mortar by Using Flow Table.

Photo 3.11: Flow Diameter of Fresh Mortar is Measured by Compass.

3.4.2.2 Time of Setting of Mortars

Test for time of setting of mortars were determined according to ASTM C191-08. The purpose of this test is to establish the initial setting time and final setting time of fresh mortars. In this test, initial and final setting time of fresh mortars are determined by vicat apparatus (Photo 3.12).

First of all fresh mortar is placed inside the metal mould located at the bottom of the vicat apparatus. The height of the metal mould is 40 mm. Afterwards, the needle is lowered to gently into contact with the surface of the mortar than the needle released quickly allow to sink into the surface of the mortar. This process is repeated until the needle penetrates inside the mortar to a point 7mm from the bottom of the mould. This is the required condition for initial setting time. Time elapsed from the begining of the process until the time when this condition is reached will indicate the initial setting time of mortar (Photo 3.13).

The required condition for final setting time is to needle penetrates inside the mortar to a point 35 mm from the bottom of the mould. Time elapsed from the begining of the test until the time when this condition is reached will indicate the final setting time of mortar.

Photo 3.12: Test for Setting Time of Fresh Mortars

Photo 3.13: Setting Time of Mortar is Determined by Vicat Apparatus.

3.4.2.3 Fresh Unit Weight of Mortars

Fresh unit weight of mortar was determined according to ASTM C-138. In this test, metal mould sizes of 100 x 100 x 100 mm were used. Firstly the empty moulds were weighted and recorded. Afterwards fresh mortar were casted into the metal moulds. Fresh mortar were placed at a one third of mould and compacted by tamping rod with 25 strokes. This process was repeated until filling. Three samples were prepared for each type of mortars. After that full moulds were weighted and recorded as a net weight (Photo 3.14). Finally the differences between net weight and empty weight is calculated (Equation 3.3) and fresh unit weight is obtained by using Equation 3.3

Fresh unit weight (kg/m^3) = Fresh weight of mortar (Kg) / Volume of moulds (m^3)……………………………………………………………………………….. (3.3)

Photo 3.14 : Samples for Testing Fresh Unit Weight of Mortars

3.4.3 Determination of Hardened Mix Properties (Physical) of Mortars

In this investigation, hardened mix properties namely, hardened unit weight, water absorption capacity, capillary water absorption capacity and drying shrinkage of hardened mortars were determined.

3.4.3.1 Hardened Unit Weight of Mortars

Hardened unit weight of mortars were determined according to ASTM C-138. In this test, metal moulds with sizes 100 x 100 x 100 mm were used. First of all, fresh mortars were cast into the metal moulds together with applied suitable compaction technique. Fresh mortar were placed at one third of mould and compacted by tamping rod with 25 strokes. This process was repeated until filling. Three samples were prepared for each type of mortars. Afterwards fresh mortar samples were placed in curing room during 24 hours and then samples were removed from metal moulds and placed into water curing tank (100 % moisture condition) during 28 days (Photo 3.14). After curing period, the samples were placed into oven (Temperature 105°C) during 24 hours to make oven-dry samples. Finally the hardened weight of samples (oven-dry) were weighted by using a balance (Photo 3.15). Hardened unit weight of mortars were established by using Equation 3.4

Hardened Unit Weight (kg/m^3) = Hardened Unit Weight of oven-dry samples (kg) / Volume of Samples (m^3)………………………………………………………… (3.4)

Photo 3.15: Samples for Determination of Hardened Unit Weight of Mortars.

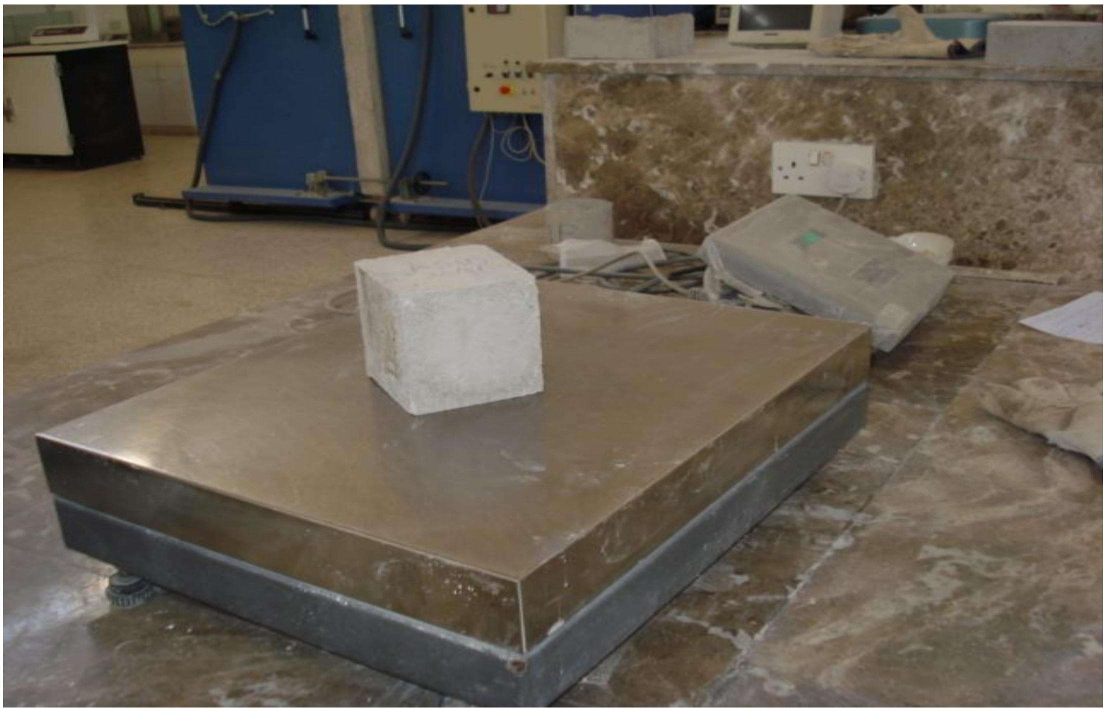


Photo 3.16: Weighing of Samples.

3.4.3.2 Percentage of Water Absorption of Mortars

Percentage of water absorption of mortars were determined according to ASTM C-20 (2010). In this test metal cube moulds of sizes of 100 x 100 x 100 mm were used. Fresh mortar samples were cast into the metal moulds and compacted. Three samples were prepared for each type of mortar. Afterwards samples were placed in the curing room for The first 24 hours and then removed from moulds and placed into water curing tank (100 % mouisture condition) during 7 days. After curing period, samples were placed into oven (temperature 105°C) during 48 hours to make oven-dry samples (stable weight) (Photo 3.17). Then the samples (oven-dry) were weighed and recorded as a initial weight (oven-dry weight). Afterwards, samples were placed completely into the water during 48 hours. Finally samples were taken out from water and weighted to obtain the saturated weight of mortar samples (Photo 3.19).

Percentage of water absorption of mortars were calculated by using Equation 3.5

Percentage of water absorption (%) = [[Saturated Weight- Oven Dry Weight (initial)] / [Oven Dry Weight (initial)]] X 100…………………………………………..(3.5)

Photo 3.17: Samples were Placed in Oven to Obtain Oven-Dry Condition.

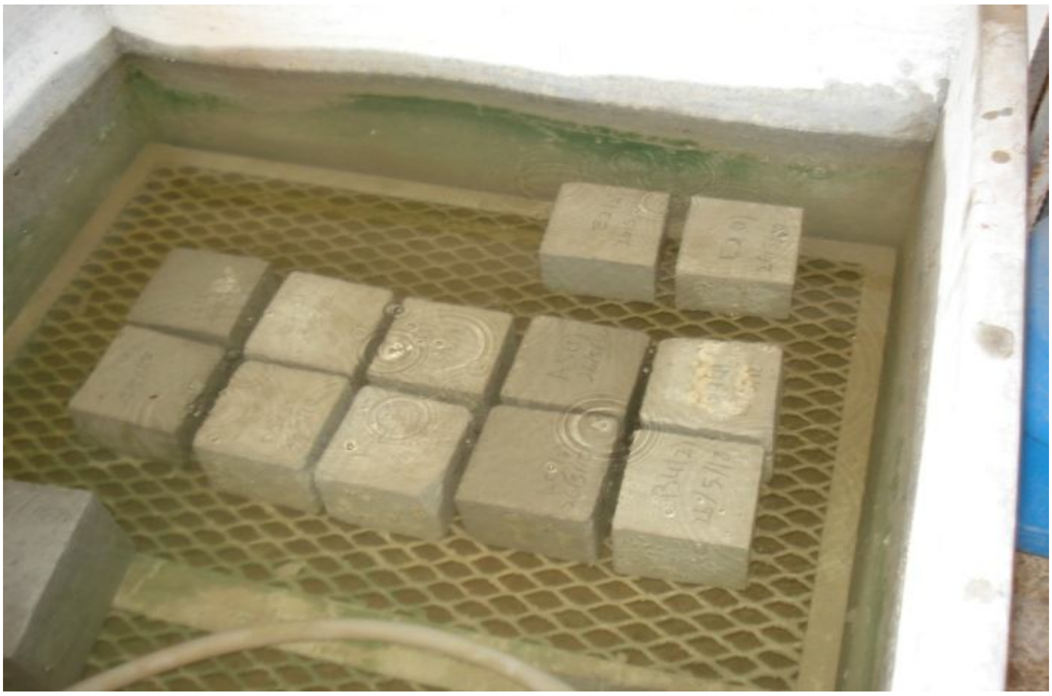


Photo 3.18: Samples were Immerced in Water for 7 days.

Photo 3.19: Saturated Weight of Samples were Measured.

3.4.3.3 Determination of Coefficient of Capillary Water Absorption of Mortar

Capillary water absorption of mortars were determined according to TS 4045. This test specifies the capacity of capillary water absorption of mortars. In this investigation mortar prisms mould consists of 40 x 40 x 160 mm were used. Fresh mortar was filled into prisms mould and placed on to the jolting table to apply required compaction. The mortar was vibrated during 60 seconds by jolting table. Three samples were prepared for each type of mortar. Afterwards samples were located in curing room during 24 hours and later on samples were removed from moulds and placed into water curing tank (100 % moisture condition) during seven days. After curing period, samples were placed into oven (temp. 105°C) to make oven-dry sample . Afterwards, samples (oven-dry) were weighted and recorded as initial mass. Thereafter samples were placed gently into water as shown in Figure 3.8. As can be seen in Photo 3.20 that samples were placed in water 5 mm deep from the surface of water (Photo 3.21) . Surface area was sinked into the water was 1600 mm^2 (40 mm x 40 mm). After this process, time-dependent mass were obtained after 24 hours (86400 second). Finally time-dependent coefficient of capillary water absorption of mortars were calculated by using Equation 3.6.

$$C_{w,s} = [m_{so,s} - m_{dry,s}] / [A_s \sqrt{t_{so}}] \times 10^6 \quad \text{...} \quad (3.6)$$

Where:

$C_{w,s}$ = Coefficient of Capillary Water Absorption ($g/m^2\ s^{0.5}$)

$m_{so,s}$ = Wet Mass (gr)

$m_{dry,s}$ = Dry Mass (gr)

A_s = Surface Area of Specimen Sinked into Water (mm^2)

t_{so} = Contact Time of Water (second)

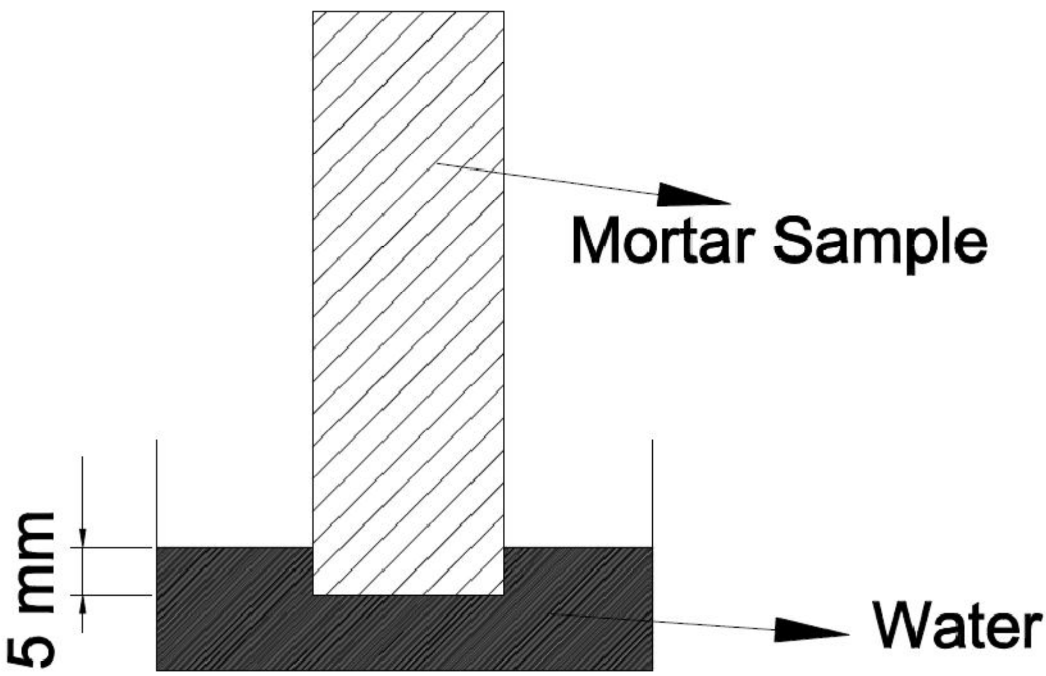


Figure 3.8: Schematic Display of Mortar Placed into Water

Photo 3.20 : Samples Placed into Water for Testing Capillary Water Absorption of Mortar.

Photo 3.21 : Test Mechanism for Determination of Capillary Water Absorption of Mortar.

3.4.3.4 Determination of Drying Shrinkage of Mortars

Drying shrinkage of mortar were determined according to ASTM C 596-09. Drying shrinkage is defined as the decrease in length of the test specimen, where the decrease is caused by any factor other than externally applied forces under stated conditions of temperature and relative humidity. This test method determines the change in length on drying of mortar bars containing hydraulic cement and standard sand.

In this investigation, mortar prisms mould consists of three gang sizes 40 x 40 x 160 mm were used. Fresh mortar was filled into the prisms mould and placed on to jolting table to apply required compaction. The mortar was vibrated during 60 seconds by jolting table. Three samples were prepared for each type of mortars. Afterwards the test specimens were located in curing room during 24 hours and later on samples were removed from moulds and small metal pieces were screwed on top and bottom of the test specimens. Thereafter, test specimens were placed into water curing tank (100% moisture condition) during 48 hours. After curing period (total 72 hours), the test specimens were removed from water tank and placed into length comparator apparatus in order to measure the initial length of test specimen (Photo3.22). Length comparator apparatus is measured length of specimens by divisions. 1 division is equal to 0.001 mm. Just after measurement of initial length, test specimens were placed in a room, where the temperature and relative humidity were 25°C and 50%, during 25 days (Photo 3.23). Finally, time-dependent length of each specimens were obtained by using length comparator apparatus after 4, 11, 18 and 25 days in air storage condition.

Percentage of drying shrinkage were calculated by Equation 3.7.

Percentage of drying shrinkage (%) = [[Initial length – time dependent length (air storage)] / [Initial length]] x 100……………………………………………..(3.7)

Photo 3.22: Length of Test Specimen is Measured by Length Comparator Apparatus

Photo 3.23 : Test Specimes are Located in Air Storage Room for 25 Days.

3.4.4 Determination of Mechanical Properties of Mortars

In this investigation, mechanical properties namely; flexural strength, compressive strength and ultrasonic pulse velocity were performed.

3.4.4.1 Flexural Strength of Mortars

Flexural strength of mortars were determined according to TS EN 1015-11. Flexure test specifies the tensile strength of test specimen. Tensile strength of mortar is determined by indirect method namely, flexure test.

In this investigation, mortar prisms mould consists of three gang sizes 40x40x160 mm were used. Fresh mortar was filled into the prisms mould and placed on to jolting table for apply required compaction. Fresh mortar was vibrated during 60 seconds by jolting table (Photo 3.24). Afterwards, test specimens were located in curing room during 24 hours and later on samples were removed from moulds and placed into water curing tank (100% moisture condition) until test ages. After curing period, test specimens were taken out of the curing tank and dried with a cloth. Thereafter, test specimens were placed on the flexural testing machine. Then force was applied on the top middle of the sample at a rate of 50 N ±10 N per second until fracture occured (Photo 3.25).The mortar samples were tested at 7 and 28 days. Three samples were tested for each ages. Therefore, six samples were prepared for each type of mortars. Flexural testing mechanisms was shown in Figure 3.9 and Equation 3.8 used in order to calculate flexural strength.

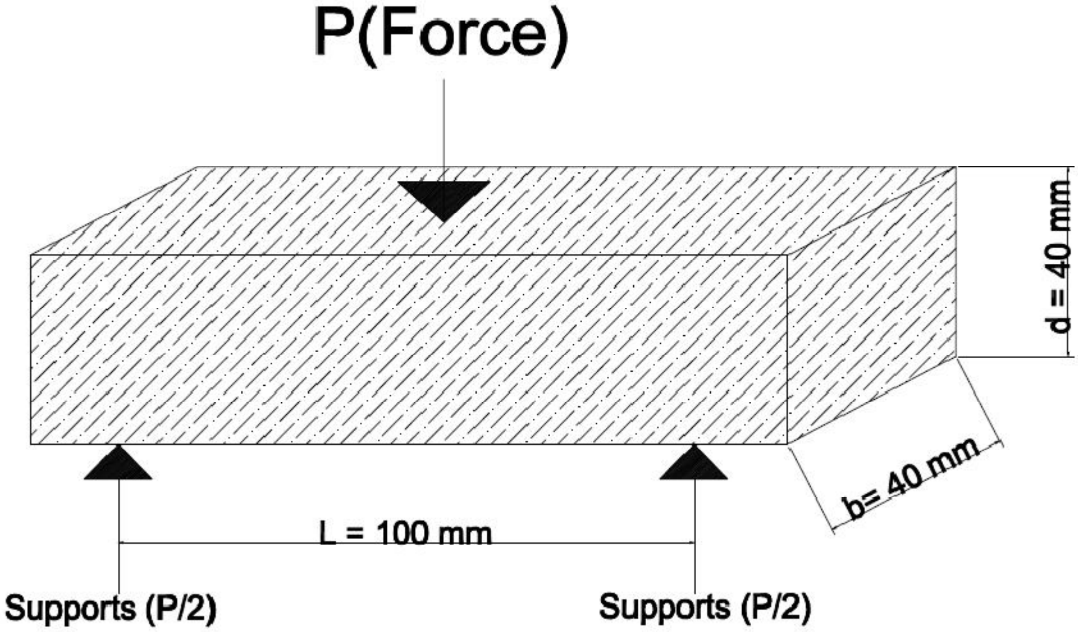


Figure 3.9 : Schematical Presentation of Flexural Testing.

$S_R = 1.5\ PL / b^3$ ……………………………………………………………..(3.8)

Where, b= Cross Section of Square Edge in mm (40 mm)

P= Applied Force (Failure Force) , in (N)

L= Length Between Two Supports in mm (100 mm)

S_R= Flexural Strength (N/mm^2)

Photo 3.24 : Mortar Samples were Compacted by Jolting Table

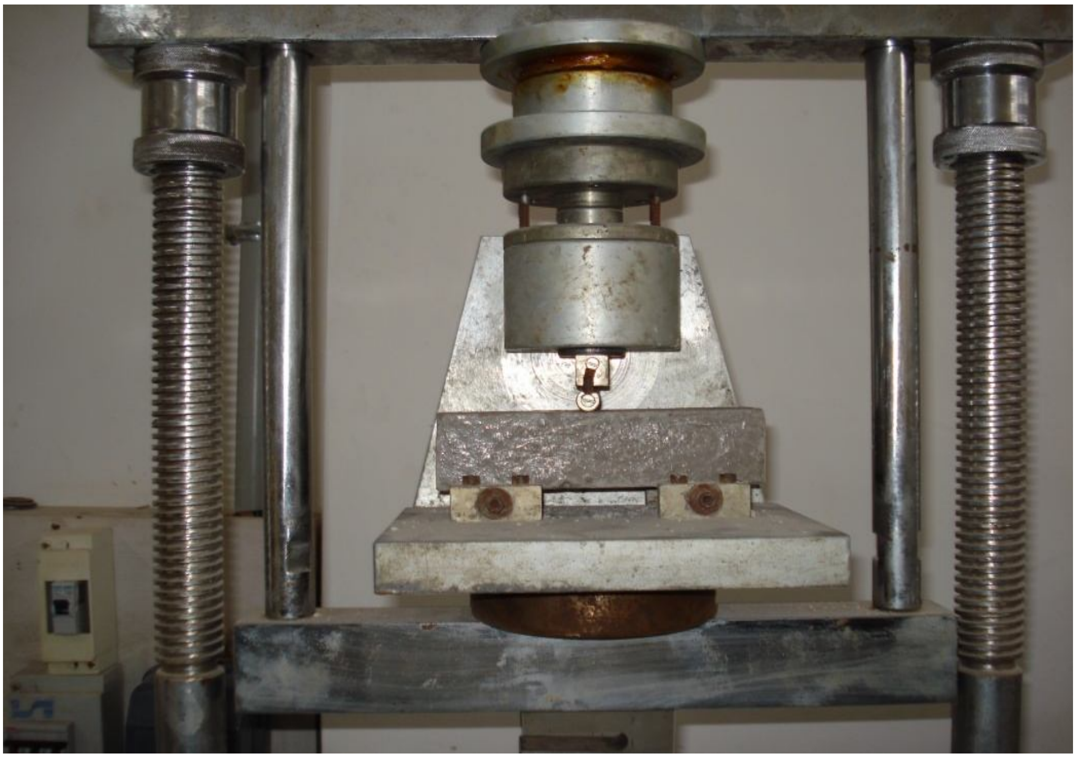


Photo 3.25: Test Specimen was Placed on Flexural Testing Machine.

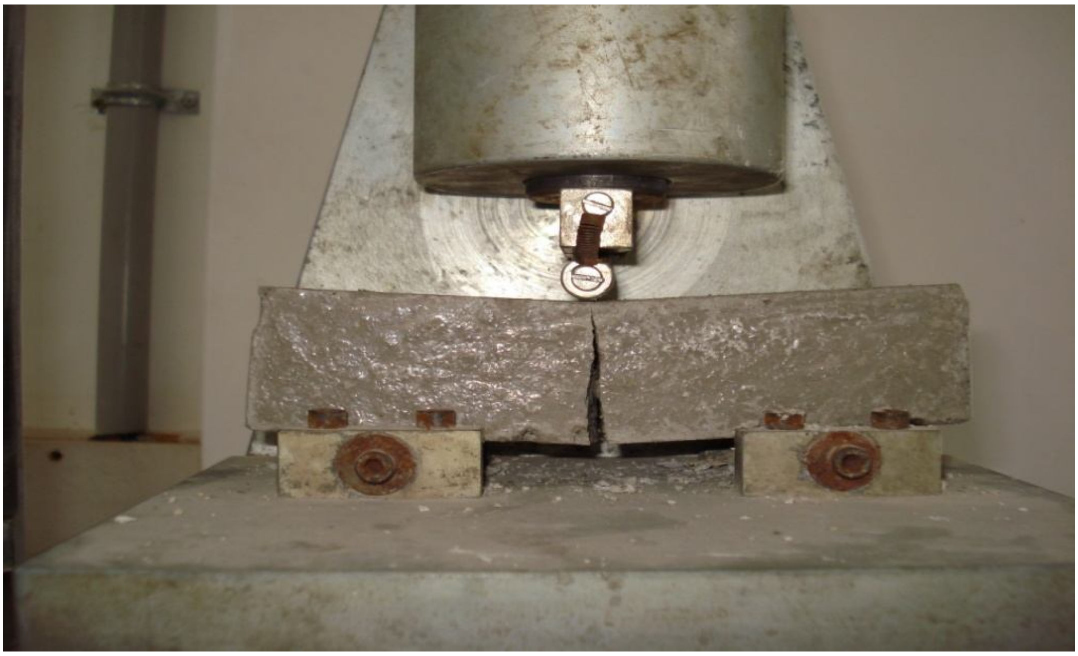


Photo 3.26 : Fracture of Sample in Flexural Test.

3.4.4.2 Compressive Strength of Mortars

Compressive strength of mortars were determined according to TS EN 1015-11. In this experiment, pieces of test specimens obtained just after the flexural strength test were used as a test specimen . In flexural strength test, prisms samples were splitted into two parts. Therefore two test specimens were obtained from one flexural strength test samples . The compressive strength of mortar samples were tested at 7 and 28 days. Three samples were tested for each ages. The test specimens were placed on to the compressive stregth test machine (Photo 3.27). The uniformly distributed force was applied on the top surface (40 x 40 mm) of test specimen at a rate of 500 N per second until fracture (Photo 3.28). Moreover schematic presentation of test mechanism is shown in Figure 3.10. Compressive strength of mortar was calculated by Equation 3.9

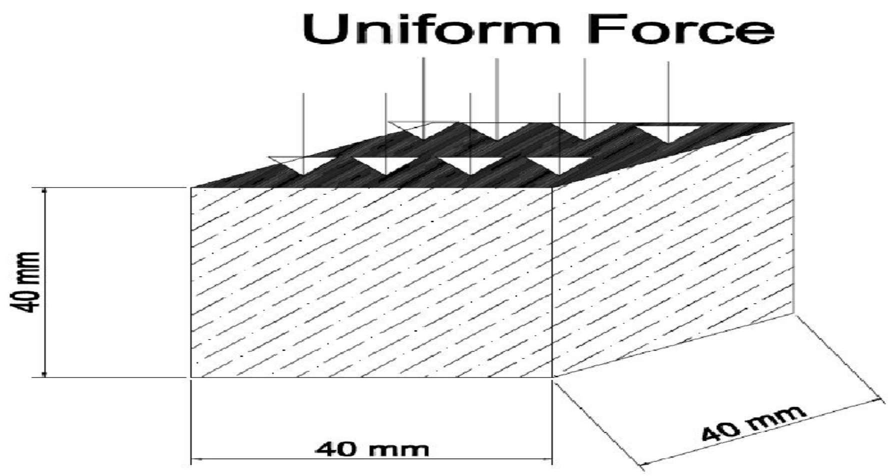


Figure 3.10 : Schematic Presentation of Compressive Strength Test Mechanism

Compressive Strength = Failure Force (N) / Surface Area (mm^2)…………….(3.9)

Photo 3.27 : Sample in Compressive Strength Test Machine.

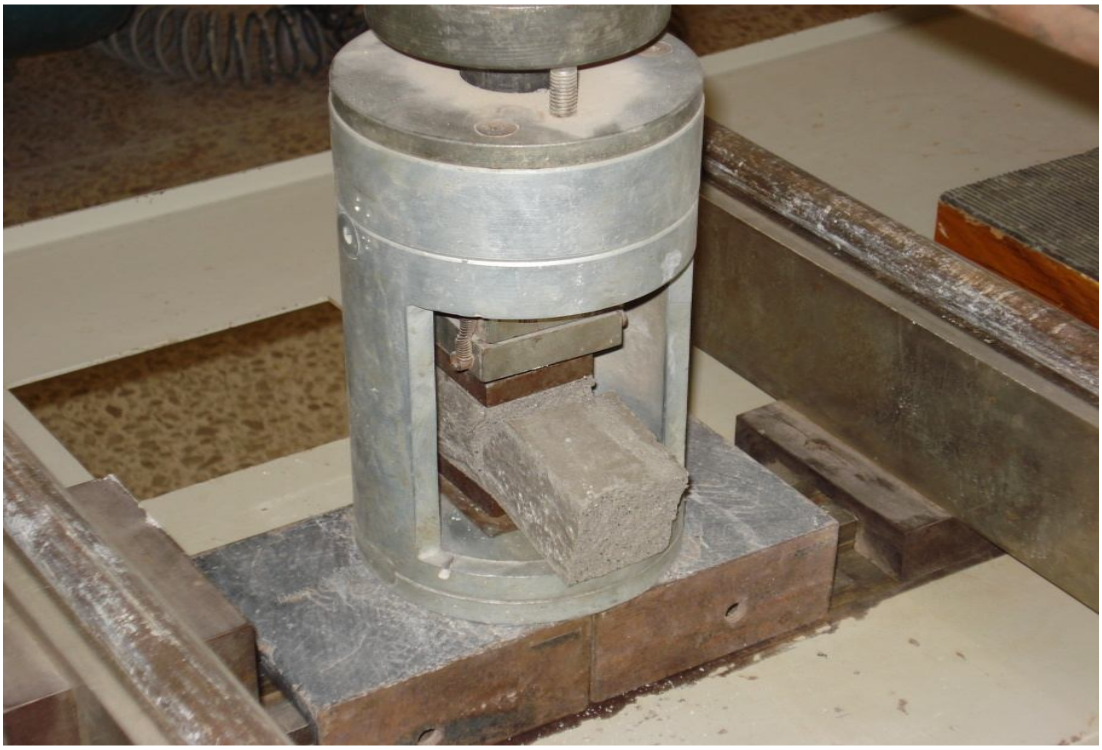


Photo 3.28 : Fracture of Test Specimen Under Compressive Loading.

3.4.4.3 Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity test was performed according to ASTM C 597-09. Pulses are generated by an electro-acoustical transducer that is held in contact with one surface of the mortar under test. After traversing through the mortar, the pulses are received and converted into electrical energy by a second transducer located a distance L from the transmitting transducer.

In this test mortar samples of sizes 100 x 100 x 100 mm were used. Three samples were tested for each type of mortar. Test specimens were cured in 100% moisture condition (water curing) during 28 days. After curing period, test specimens were taken out of water tank and dried with a cloth (Photo 3.29). Thereafter, grease is used to eliminate voids on the surface, where transmitting and receiving transducer located on test specimen. Later on the transmitting and receiving transducer were placed on opposite surfaces of test specimen (Photo 3.30). Afterwards pulse generator (pundit) was switch on and pulses generated by pundit was transmitted through test specimen from transmitting transdecur to receiving transdecur. Schematic of pulse velocity test mechanism were shown in Figure 3.11. The transmit time T of pulse waves is measured electronically. The pulse velocity V is calculated by dividing path length (L) by Transmit time (T) as explained in Equation 3.10.

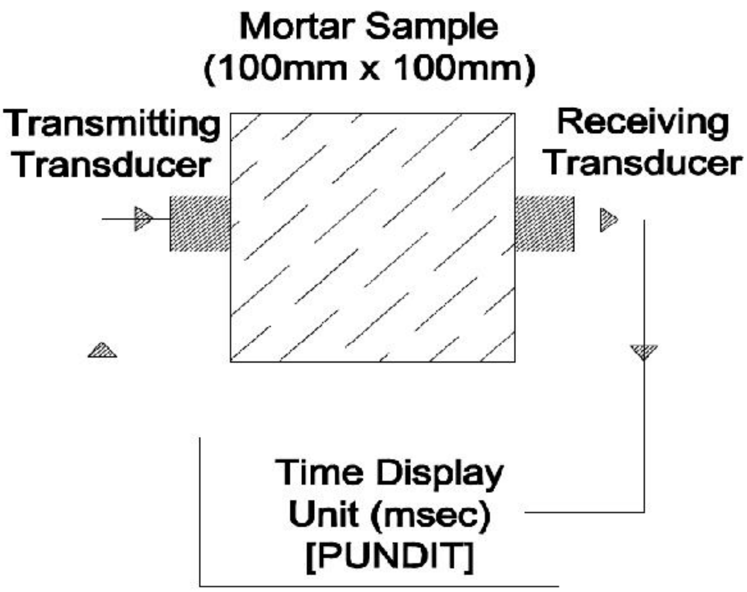


Figure 3.11: Schematic Presentation of Pulse Velocity Test Mechanism.

Pulse velocity is calculated as follows:

$V = L / T$………………………………………………………………….. (3.10)

Where,

V = Pulse velocity, km/s

L= Path length (km)

T = Transmit time (s).

Photo 3.29: Test Specimens (100x100x100 mm) for Pulse Velocity Test

Photo 3.30: Pulse Velocity Test Performed on Mortar Sample.

3.4.5 Determination of Thermal Conductivity Coefficient of Different Wall Systems by Calibrated Hot-Box Device.

3.4.5.1 Calibrated Hot-Box Device

Calibrated Hot-Box device is used to determine the coefficient of thermal conductivity of walls . This test facilities is performed according to TS EN ISO 8990. The Hot-Box consists of two highly insulated chambers namely, cold chamber and hot chamber that clamped tightly together to surround the test wall. Air in each chamber is conditioned by heating and cooling equipment to obtain desired temperatures on each side of the wall. The chambers (cold and hot) are cycled between various temperatures. These temperature cycles can be programmed to simulate outdoor climatic conditions. Temperatures are measured by termo-couples with 0.1°C sensibility. There are 9 thermo-couples existing on each chamber to measure the surface temperature of wall sample and 3 thermo-couples available on each chamber to measure the ambiance temperature of chambers. All data (surface and ambent temperatures) are transferred to computer and coefficient of thermal conductivity is calculated. Coefficient of thermal conductivity of wall can be determined between 0.01 and 4 W/mK. Figure 3.16 shows the schematic presentation of Hot-Box test mechanism.

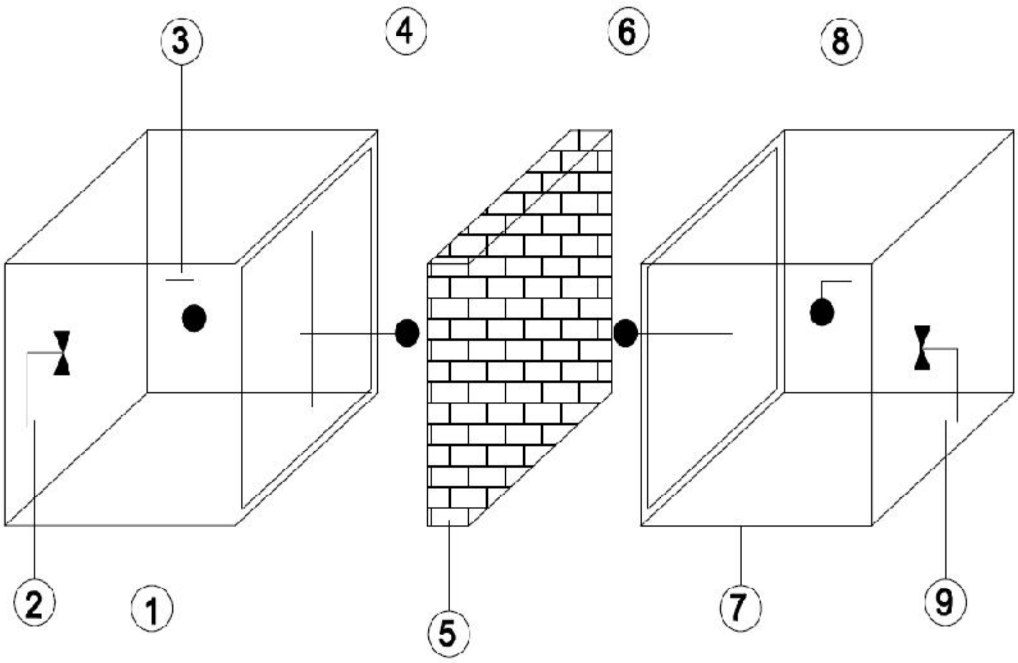


Figure 3.12: Schematic Presentation of Hot-Box Test Mechanism.

Where,

1. Cold Chamber
2. Freezer Fan
3. Thermo-couples (3 unit) to measure the ambient temperature of cold chamber.
4. Thermo-couples (9 unit) for measure the surface temperature (cold) of wall sample.
5. Wall specimen (1.2m x 1.2m)
6. Thermo-couples (9 unit) to measure the surface temperature (hot) of wall sample.
7. Hot chamber
8. Thermo-couples (3 unit) to measure the ambient temperature of hot chamber
9. Heater fan

3.4.5.1 Wall Specimens and Test Procedure

In this investigation, seven different wall systems by means of different applied mortar/plaster and block types were formed in order to determine the coefficient of thermal conductivity of wall specimens. Three different sizes of pumice-blocks were used in this investigation. As explained before, two different types of mortar and plaster, namely, lightweight pumice mortar/plaster and limestone mortar/plaster (traditional) were applied on masonry units. Three wall specimens made of pumice block and pumice mortar/plaster were formed and three wall specimens made of pumice-block and limestone mortar/plaster (traditional) were formed to designate the coefficient of thermal conductivity. Moreover one wall specimen made of clay bricks of sizes 100 x 200 x 300 mm together with applied limestone mortar/plaster (traditional) was formed. Therefore seven different wall systems were created in order to establish the coefficient of thermal conductivity and make comparison among themsefl (Table 3.19).

Table 3.19: Types of Wall systems.

Mortar / Plaster	Wall Type No	Masonry Unit	Dimensions (mm)	Thickness (mm)
Pumice	1	Pumice -Block	150 X 390 X 185	150
	2	Pumice -Block	190 x 390 x 185	190
	3	Pumice -Block	250 x 390 x 185	250
Limestone (Traditional)	4	Pumice -Block	150 X 390 X 185	150
	5	Pumice -Block	190 x 390 x 185	190
	6	Pumice -Block	250 x 390 x 185	250
	7	Clay Brick	100 x 200 x 300	200

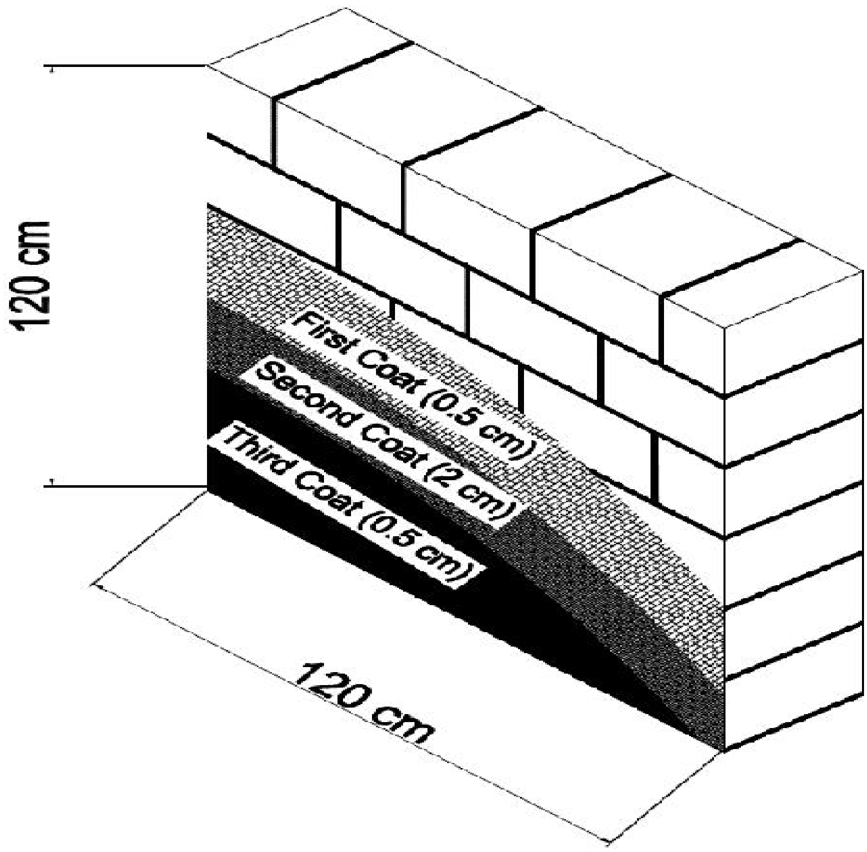
The sizes of wall specimens to be formed were 1.2 m x 1.2 m (Surface Area = 1.44 m^2).

Joint mortars and plasters were produced according to mix proportions as explained in section 3.3.2. Larger volume of mixer was used to produce required amount of mortar (Photo 3.31.)

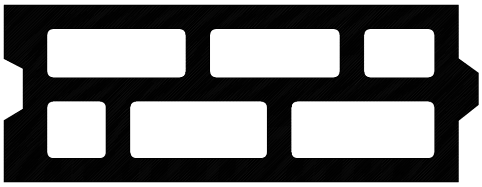
The first step to form a wall specimen was to build up the masonry units by joint mortar (Photo 3.32). Regularity of wall specimen was checked by spirit level (Photo 3.33). Constructed wall specimens were kept wet during 3 days. Second step was to appy first coat plaster on wall specimens. First coat plaster was produced according to mix proportion as explained in section 3.3.2. First coat plaster also called rough rendering due to application technique. The thickness of first coat applied on both surface wall specimen was around 5mm (Photo 3.34). Wall specimens were kept wet during 3 days before application of second coat plaster.

Afterwards, second coat plaster was produced according to determined mix proportions (section 3.3.2) and applied on wall specimens. Second coat is also called main plaster by means of wall plastering. The thickness of second coat applied on both surface wall specimens were around 20 mm (Photo 3.35). Wall specimens were kept wet for 3 days before application of third coat plaster.

The final step in point of generation of wall specimen was the application of third coat plaster. Thrid coat plaster is also called finishing (final coat) plaster in wall plastering. The main purpose of third coat plaster is to make smooth surface. As explained before, ready-mixed plaster was applied as a third coat plaster as applied in the market in Cyprus. Ready-mixed plaster doesn't contain aggregate. Ready-mixed plaster is produced by adding requied amount of water. Mass of a bag of product (ready-mixed plaster) is 20 kg. 5 kg of water is added to 20 kg of product in order to produce ready-mixed third coat plaster. This mix proportion is specific and it is not possible to use different mix proportion. The thickness of third coat (finishing) plaster applied on wall specimen was around 5 mm (Photo 3.36). Ready Mixed Plaster was applied on both surface of walls. After this stage (third coat plaster) , the wall specimens were generated in order to tests based on thermal conductivity. Figure 3.13 shows the schematic presentation of wall specimens as well as technical properties of wall systems.



(a) Schematic presentation of wall specimen



Masonry Unit : Pumice –Block

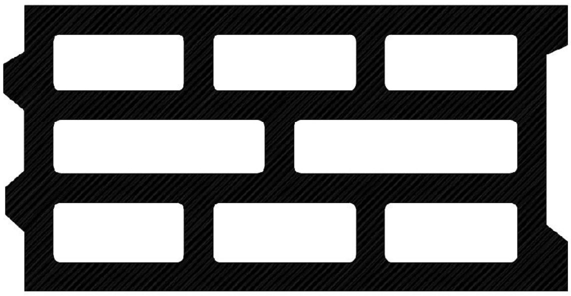
Dimensions: 150 x 390 x 185 mm

Thickness: 150 mm

Type of Joint Mortar: Pumice Mortar

Types of Plaster: Pumice Plaster

(b) Technical properties of type 1 wall specimen



Masonry Unit : Pumice – Block

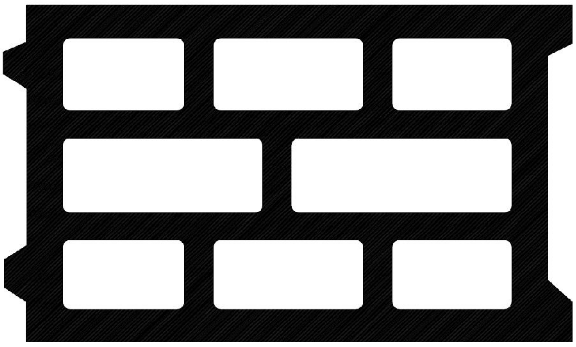
Dimensions : 190 x 390 x 185 mm

Thickness: 190 mm

Type of Joint Mortar: Pumice Mortar

Types of Plaster: Pumice Plaster

(c) Technical properties of type 2 wall specimen



Masonry Unit: Pumice- Block

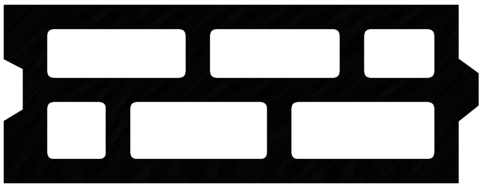
Dimensions: 250 x 390 x 185 mm

Thickness: 250 mm

Type of Joint Mortar: Pumice Mortar

Types of Plaster: Pumice Plaster

(d) Technical Properties of type 3 wall specimen.



Masonry Unit: Pumice-Block

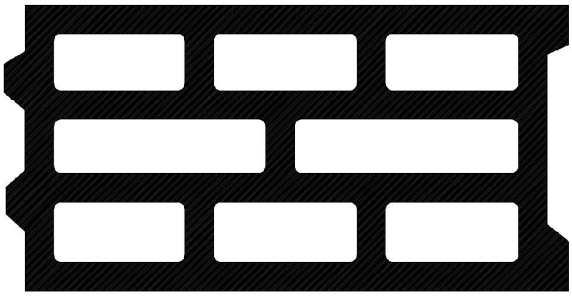
Dimensions: 150 x 390 x 185 mm

Thickness: 150 mm

Type of Joint Mortar: Limestone Mortar (Traditional)

Types of Plaster: Limestone Plaster (Traditional)

(e) Technical properties of type 4 wall specimen.



Masonry Unit: Pumice-Block

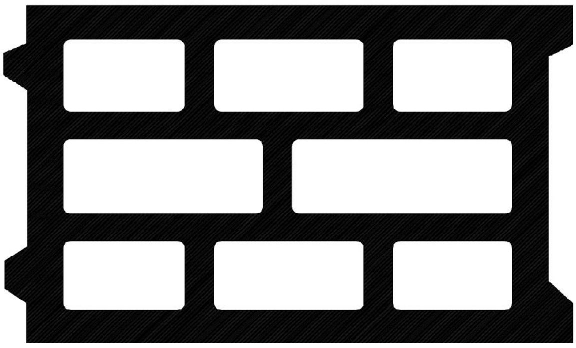
Dimensions: 190 x 390 x 185 mm

Thickness: 190 mm

Type of Joint Mortar: Limestone Mortar (Traditional)

Types of Plaster: Limestone Plaster (Traditional)

(f) Technical properties of type 5 wall specimen



Masonry Unit: Pumice- Block

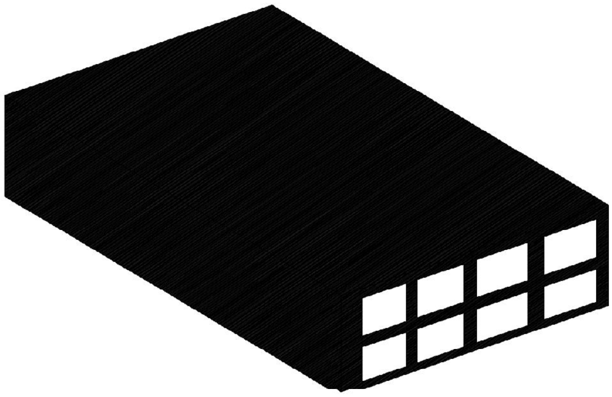
Dimensions: 250 x 390 x 185 mm

Thickness: 250 mm

Type of Joint Mortar: Limestone Mortar (Traditional)

Types of Plaster: Limestone Plaster (Traditional)

(g) Technical properties of type 6 wall specimen



Masonry Unit: Clay Brick

Dimensions: 200 x 300 x 100mm

Thickness: 200 mm

Type of Joint Mortar: Limestone Mortar (Traditional)

Types of Plaster: Limestone Plaster (Traditional)

(h) Technical Properties of type 7 wall specimen (Traditional wall system)

Figure 3.13 : Schematic Presentation and Technical Properties of Wall Systems

Photo 3.31: Mortar Produced by Large Mixer


Photo 3.32: Construction of Wall Specimens.


Photo 3.33: Levelling of Walls.

Photo 3.34: Wall Specimen Made with Clay Brick.

Photo 3.35: First Coat Plastering Applied on Wall Specimen.

Photo 3.36: Second Coat Plastering is Applied on Wall Specimen.

Photo 3.37: Finishing of Second Coat Plastering.

Photo 3.38: Third Coat Plastering (Ready-Mixed) (Final Coat) Applied on Wall Specimen.

Photo 3.39: Different Wall Specimens

Photo 3.40: Wall Specimens are Ready for Thermal Conductivity Coefficient Test.

Coefficient of thermal conductivity of wall specimens were determined according to TS EN ISO 8990. In this investigation calibrated Hot-Box system was used. Wall specimen was placed in between hot chamber and cold chamber of Hot-Box device (Photo 3.41). Chambers were tightly surround the wall specimen (Photo 3.42) .Exterior surfaces (edges) of wall specimens were covered by high insulating material in order to minimize the heat loss within wall specimen (Photo3.43). Afterwards, desired temperatures in both chambers were programmed by the computer system of device. In this investigation, temperature of hot chamber was programmed to be 42°C and temperature of cold chamber was programmed to be 20°C. Duration of test was programmed to 12 hours. Required test duration is 12 hours according to TS EN ISO 8990. Therefore wall specimens were exposed to hot and cold weather conditions, numerically, 42°C and 20°C during 12 hours. Main screen of hot-box program was displayed in Photo 3.48. Temperature on both sides of walls were measured and transferred to program of the equipment in order to calculate coefficient of thermal conductivity (Photo 3.44).

Photo 3.41: Hot-Box Device

Photo 3.42: Thermo-Couples to Measure the Surface Temperature of Wall Specimen.

Photo 3.43: Wall Specimen Placed Between Hot (Left Side) and Cold (Right Side) Chambers.

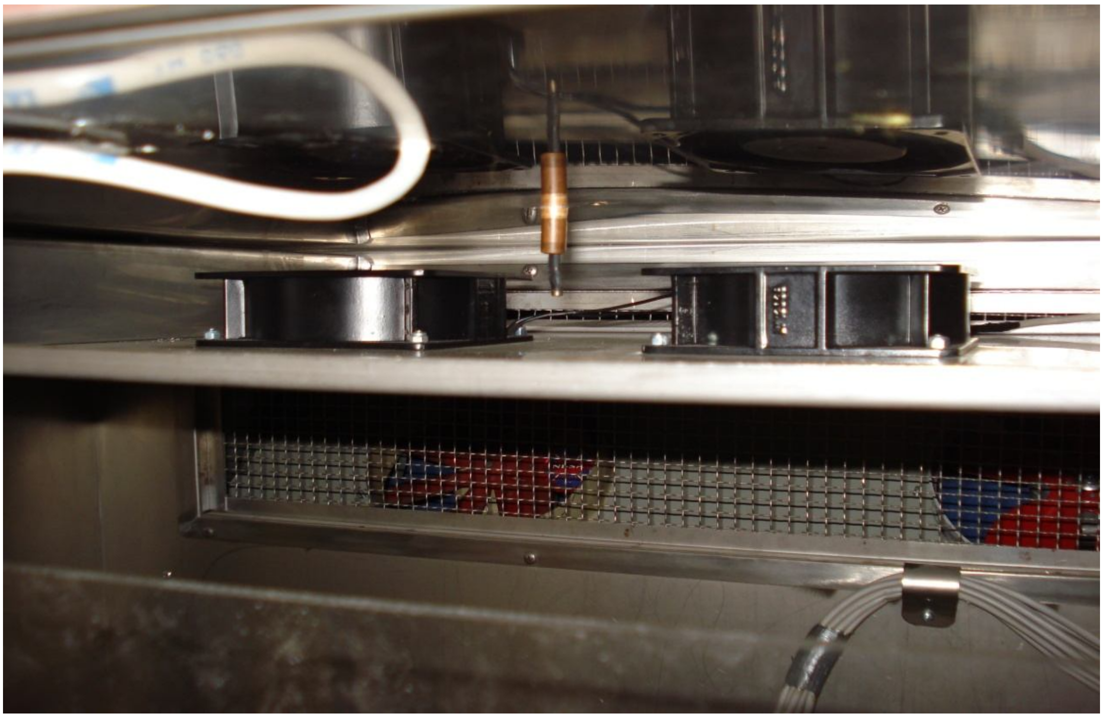


Photo 3.44: Thermo-Couple to Measure the Ambient Temperature of Chamber.

Photo 3.45: Wall Specimen is Placed on Hot-Box Device.

Photo 3.46: Wall Specimen Placed Tightly Between Hot Chamber and Cold Chamber.

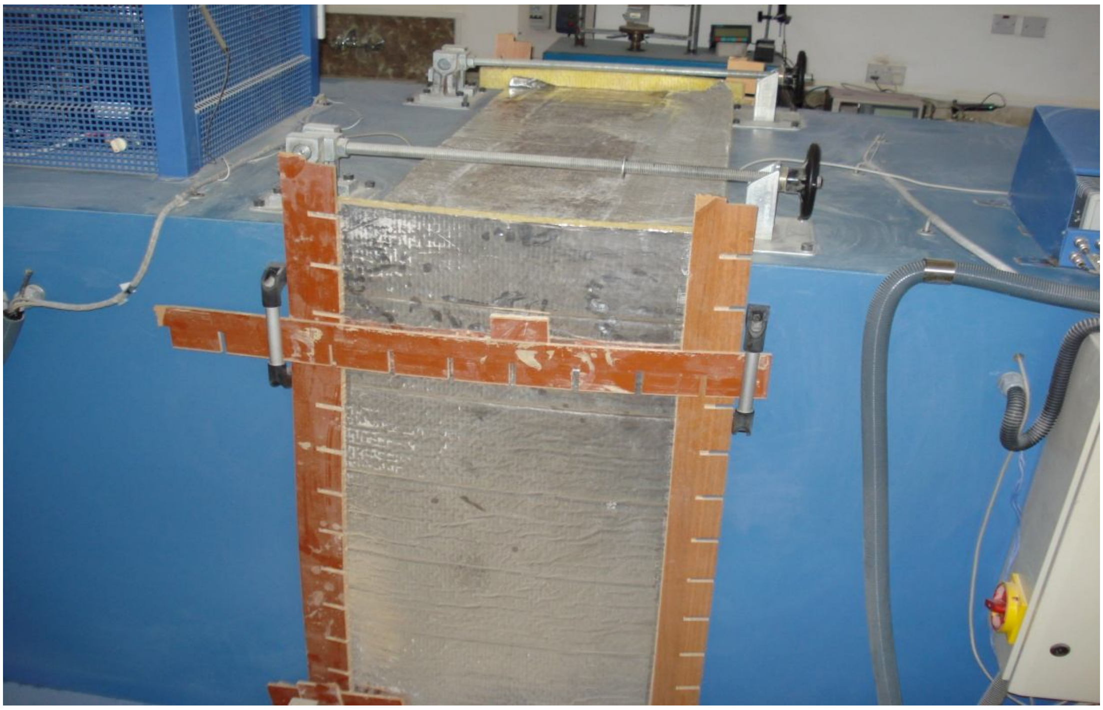


Photo 3.47: Exterior Edges of Wall Specimen Covered by Insulating Material to Minimize the Heat Loss Within Material.

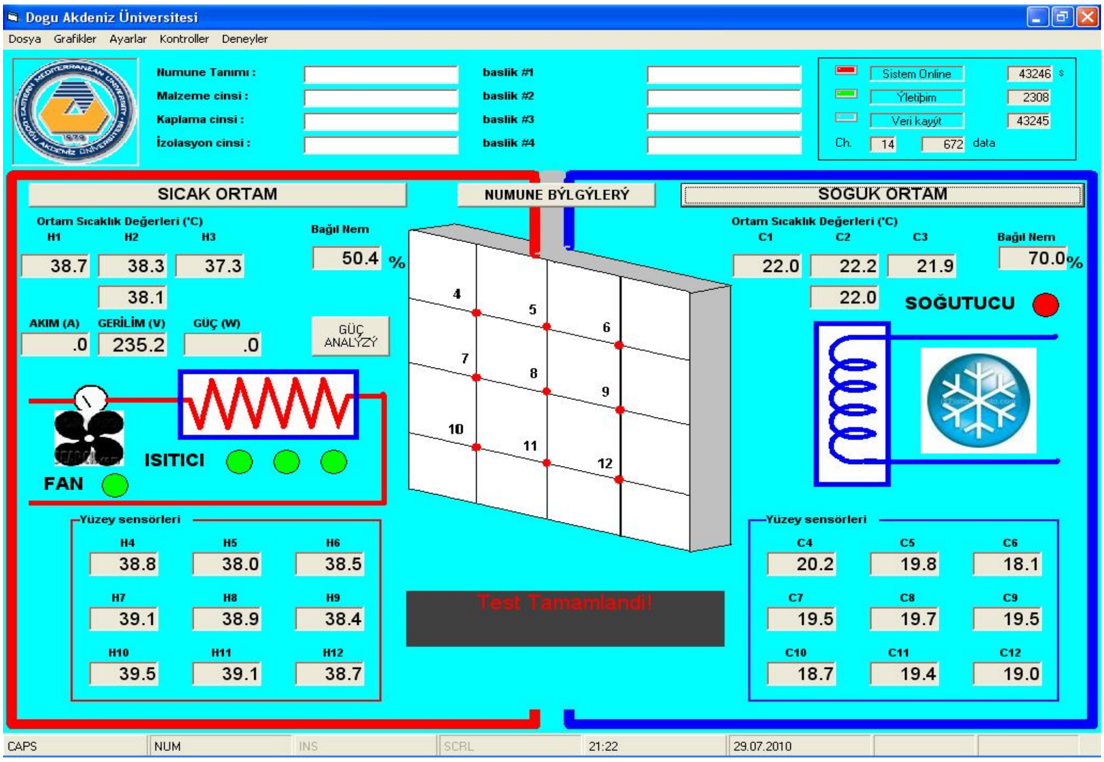


Photo 3.48: Main Screen of Hot-Box Computer Software

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter deals with the experimental test results of fresh mix properties, hardened mix properties (physically) and mechanical properties of mortars made of pumice aggregate and limestone (traditional) aggregate. Experimental test results of consistency, time of setting, fresh unit weight, hardened unit weight, percentage of water absorption, capillary water absorption, percentage of drying shrinkage, flexural strength, compressive strength and ultrasonic pulse velocity test for mortar and plaster are given. Furthermore, test results of coefficient of thermal conductivity of wall specimens made of different type of mortar / plaster combinations and masonry units were also explained in this chapter.

All experimental test results related both mortar / plaster and wall specimen (coefficient of thermal condcutivity) are compared among themselves.

4.2 Analysis of Test Results

4.2.1 Consistency of Fresh Mortar Test

The results of consistency of fresh mortar test for pumice mortars and limestone mortars (traditional) are given in Table 4.1 and 4.2, respectively. Figure 4.1 shows the comparasion of first coat plastering mortar made of pumice and limestone aggregate. Figure 4.2 shows the comparasion of joint mortar and second coat plastering mortar made of pumice and limestone aggregate.

From Figure 4.1, the followings can be said:

1. Workability limit is specified as 130 mm (flow diameter) according to test standard. Lower than 130 mm means no workable mortar. It is observed from Figure 4.1, workability duration of traditional and pumice mortar are 5.2 hr, and 4.1 hr, respectively.
2. Traditional first coat plastering mortar has higher workability duration compared to pumice first coat plastering mortar. Because rate of stiffening is higher in pumice mortar due to higher water absorption capacity of pumice aggregate. Therefore amount of water directly effects the workability of mortar.
3. Initial flow diameter of mortars are almost the same. In mix proportioning, amount of water was determined by taking into consideration of initial consistency of fresh mortars. Mortars both made of limestone and pumice aggregates were produced with the same consistence.

From Figure 4.2, the followings can be said:

1. Workability duration of traditional joint mortar / second coat plastering and pumice joint mortar / second coat plastering mortars are 4.2 hr, and 3 hr, respectively.
2. Traditional joint mortar / second coat plastering mortar has higher workability duration compared to pumice joint mortar / second coat

plastering mortar. Because rate of stiffening is higher in pumice mortar due to higher water absorption capacity of pumice aggregate.

3. Initial flow diameter of mortars are almost same. In mix proportioning, amount of water was determined by taking into consideration of initial consistency of fresh mortars. Mortars both made of limestone and pumice aggregates were produced with the same consistence.
4. Initial consistency (initial flow diameter) of first coat plastering mortars are much more compared to second coat plastering / joint mortar which depends on the application technique. Because first coat plastering is also known as rough rendering and applied on wall in rough form.

Table 4.1: Consistency Test Results of Pumice Mortar

		Duration (Hour)										
	Mortar Type	**00:00**	**01:00**	**02:00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**	**08:00**	**09:00**	**10:00**
Flow Diameter (mm)	First Coat	210	187	169	153	142	132	120	107	100	100	100
	Second Coat / Joint Mortar	165	152	150	141	132	125	120	113	100	100	100

Table 4.2: Consistency Test Results of Limestone Mortar (Traditional)

		Duration (Hour)										
	Mortar Type	**00:00**	**01:00**	**02:00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**	**08:00**	**09:00**	**10:00**
Flow Diameter (mm)	First Coat	207	173	156	143	131	115	104	100	100	100	100
	Second Coat/ Joint Mortar	160	139	135	130	118	110	103	100	100	100	100

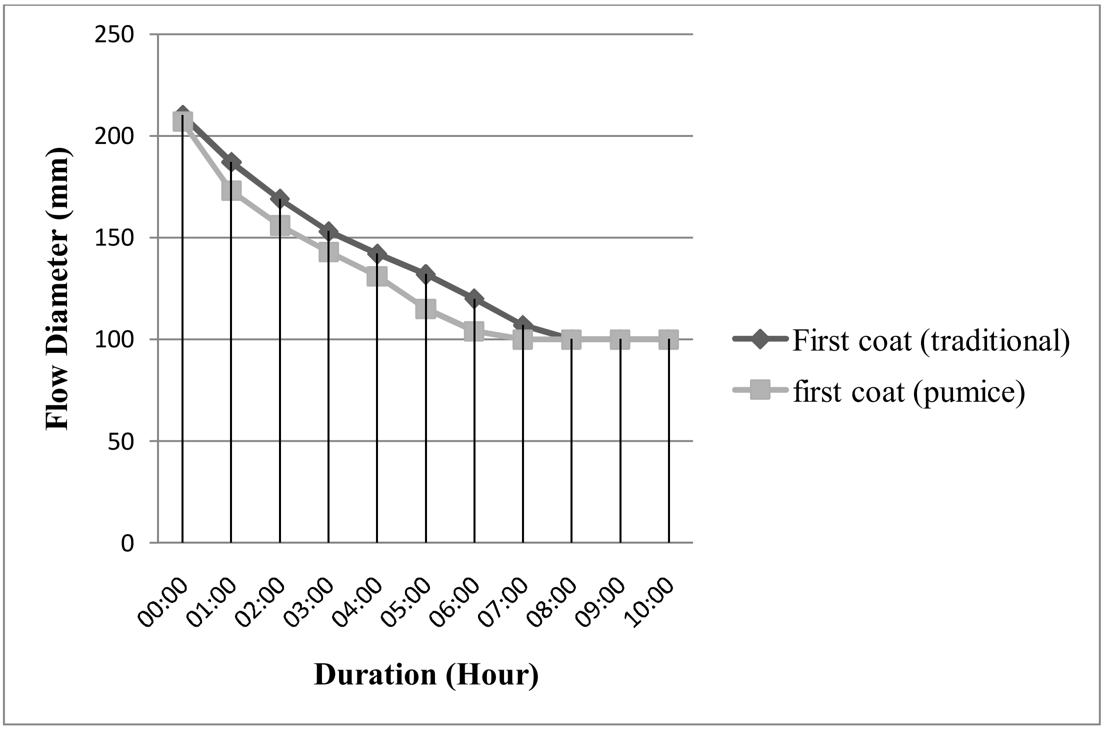


Figure 4.1: Flow Diameter of First Coat Plastering Mortar of Traditional and Pumice Mortar.

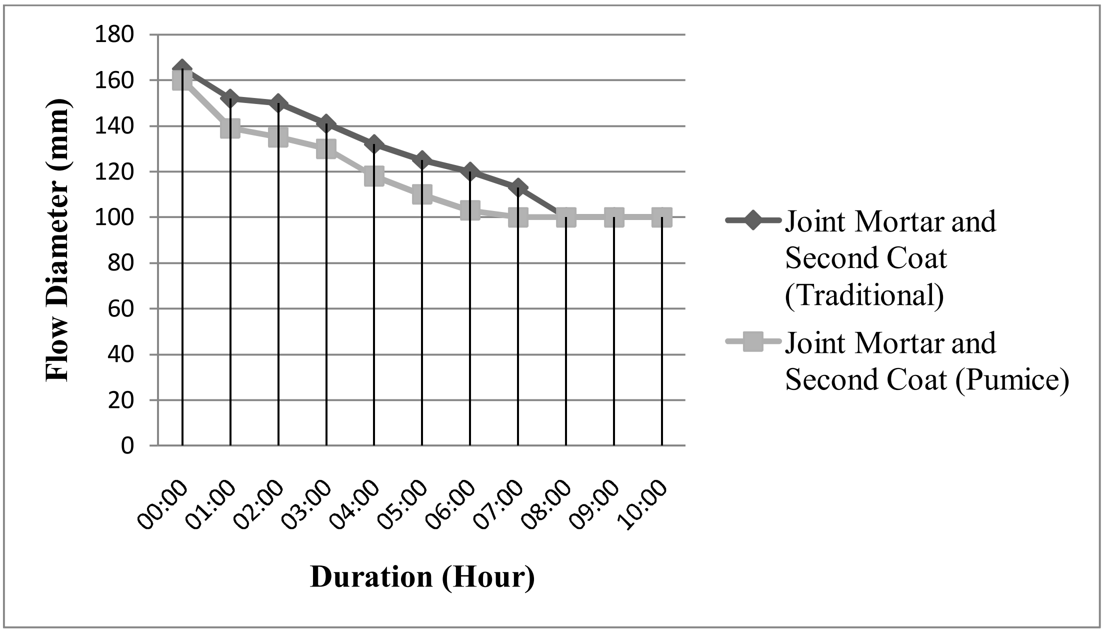


Figure 4.2: Flow Diameter of Joint Mortar /Second Coat Plastering Mortar of Traditional and Pumice Mortar.

4.2.2 Time of Setting of Mortars

The results of setting times of limestone mortars (traditional) and pumice mortars are given in Table 4.3 and Table 4.4 respectively. Figure 4.3 shows the comparasion of initial setting times of mortars. Figure 4.4 shows the comparasion of final setting times of mortars.

From Figure 4.3, the following can be said:

1. Initial setting times of first coat and second coat plastering / joint mortar made of limestone aggregate are 342 minutes and 365 minutes, respectively.
2. Initial setting times of first coat and second coat plastering / joint mortar made of pumice aggregate are 256 minutes and 222 minutes respectively.
3. Limestone mortars (traditional) has higher initial setting times compared to pumice mortars for the case of both first coat and second coat plastering / joint mortars.
4. Consistency of first coat plastering mortars is higher compared to second coat plastering /joint mortar which depends on application technique. Althought lime causes to increase the time of setting, first coat plastering mortars contains much more amount of water compared to second coat plastering mortars. It is known that higher amount of water results higher setting time. Therefore difference of initial setting time between first coat and second coat plastering is not obvious.

From Figure 4.4 the following can be said:

1. Final setting times of first coat and second coat plastering / joint mortar made of limestone aggregate are 486 minutes and 445 minutes respectively.
2. Final setting times of first coat and second coat plastering / joint mortar made of pumice aggregate are 345 minutes and 310 minutes respectively.
3. Limestone mortars (traditional) has higher final setting times compared to pumice mortars fort he cases of both first coat and second coat plastering / joint mortar.
4. Consistency of first coat plastering mortars is higher compared to second coat plastering /joint mortar which depends on application technique. Althought lime causes to increase the time of setting, first coat plastering mortars contains much more amount of water compared to second coat plastering mortars. It is known that higher amount of water results higher setting time. Therefore difference of final setting time between first coat and second coat plastering is not obvious.

Table 4.3: Time of Settings of Limestone Mortars (Traditional)

Mortar Type	Initial Setting Time (min)	Final Setting Time (min)
First Coat	342	486
Second Coat / Joint Mortar	365	445

Table 4.4: Time of Settings of Pumice Mortars

Mortar Type	Initial Setting Time (min)	Final Setting Time (min)
First Coat	256	345
Second Coat / Joint Mortar	222	310

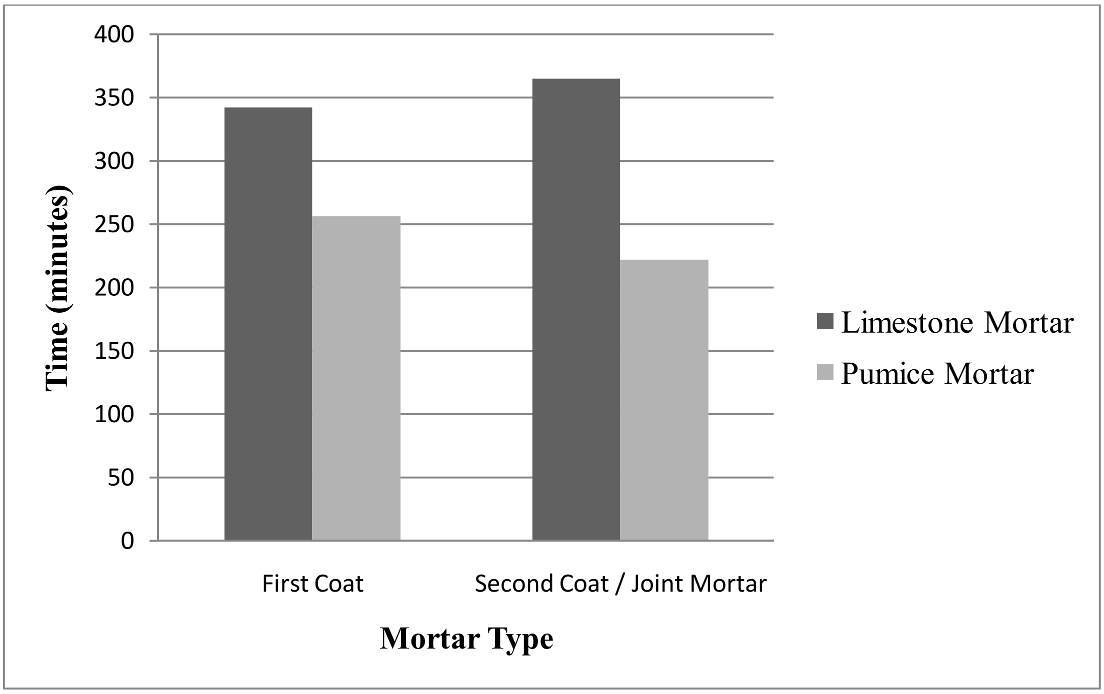


Figure 4.3: Comparasion of Initial Setting Times of Mortars

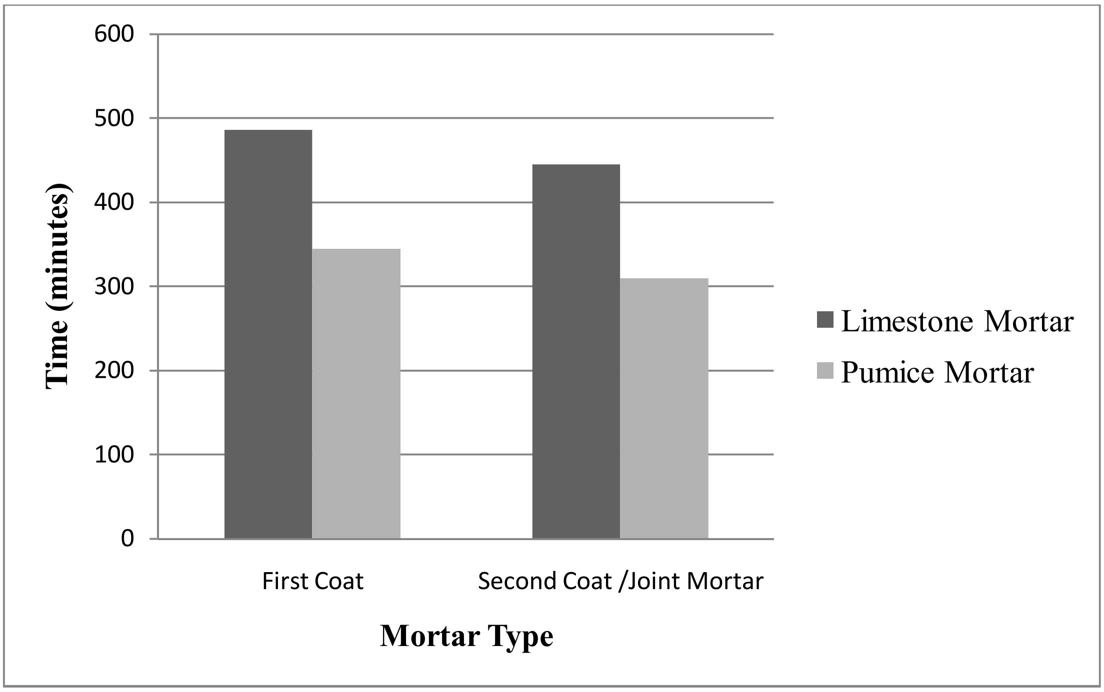


Figure 4.4: Comparasion of Final Setting Times of Mortars.

4.2.3 Fresh Unit Weight Test

The results of fresh unit weight of limestone mortars (traditional) and pumice mortars are given in Table 4.5 and Table 4.6, respectively. Figure 4.5 shows the comparasion of fresh unit weight of mortars.

From Figure 4.5 the following can be said:

1. Average fresh unit weight of first coat and second coat plastering / joint mortar made of limestone aggregate are 2128.3 kg/m^3 and 2299.1 kg/m^3 respectively.
2. Average fresh unit weight of first coat and second coat plastering / joint mortar made of pumice aggregate are 1380.3 kg/m^3 and 1502.7 kg/m^3 respectively.
3. Limestone mortars (traditional) has higher fresh unit weight compared to pumice mortars fort he cases of both first coat and second coat plastering / joint mortar.
4. Fresh unit weight of limestone mortars is 1.5 times higher compared to pumice mortars. Because the bulk density of pumice aggregate is lower compared with limestone aggregate.

Table 4.5: Fresh Unit Weight of Limestone Mortars

Type	**No**	**Fresh weight (kg)**	**Fresh Unit Weight (kg/m^3)**
First Coat	1	2.131	2131
	2	2.116	2116
	3	2.138	2138
AVERAGE		2.128	**2128.3**
Second Coat / Joint Mortar	1	2.309	2309
	2	2.274	2274
	3	2.315	2315
AVERAGE		2.299	**2299.3**

Table 4.6: Fresh Unit Weight of Pumice Mortars

Type	**No**	**Fresh weight (kg)**	**Fresh Unit Weight (kg/m^3)**
First Coat	1	1.367	1367
	2	1.415	1415
	3	1.359	1359
AVERAGE		1.380	**1380.3**
Second Coat / Joint Mortar	1	1.544	1544
	2	1.483	1483
	3	1.481	1481
AVERAGE		1.503	**1502.7**

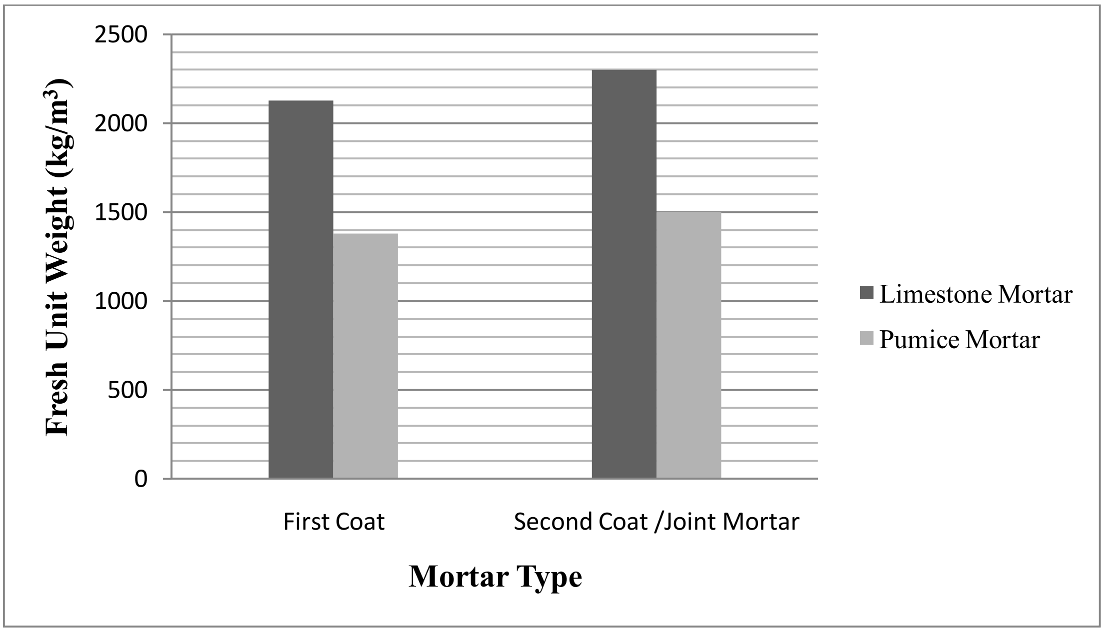


Figure 4.5: Comparasion of Fresh Unit Weight of Limestone and Pumice Mortars

4.2.4 Hardened Unit Weight Test

The results of hardened unit weight of limestone mortars (traditional) and pumice mortars are given in Table 4.7 and Table 5.8, respectively. Figure 4.6 shows the comparasion of hardened unit weight of mortars.

From Figure 4.6, the following can be said:

1. Hardened unit weight of first coat and second coat plastering / joint mortar made of limestone aggregate are 1970.7 kg/m^3 and 1901.3 kg/m^3 respectively.
2. Hardened unit weight of first coat and second coat plastering / joint mortar made of pumcei aggregate are 1107.3 kg/m^3 and 1196.7 kg/m^3 respectively.
3. Limestone mortars (traditional) has higher hardened unit weight compared to pumice mortars for the cases of both first coat and second coat plastering / joint mortar.
4. Hardened unit weight of limestone mortars is 1.65 times higher compared to pumice mortars. Because the bulk density of pumice aggregate is considerably lower compared to limestone aggregate.

Table 4.7: Hardened Unit Weight of Limestone Mortars

Type	No	Hardened weight (kg)	Hardened Unit Weight (kg/m^3)
First Coat	1	1.981	1981
	2	1.948	1948
	3	1.983	1983
AVERAGE		1.971	**1970.7**
Second Coat / Joint Mortar	1	1.877	1877
	2	1.909	1909
	3	1.918	1918
AVERAGE		1.901	**1901.3**

Table 4.8: Hardened Unit Weight of Pumice Mortars

Type	No	Hardened weight (kg)	Hardened Unit Weight (kg/m^3)
First Coat	1	1.085	1085
	2	1.17	1170
	3	1.067	1067
AVERAGE		1.107	**1107.3**
Second Coat / Joint Mortar	1	1.224	1224
	2	1.187	1187
	3	1.179	1179
AVERAGE		1.197	**1196.7**

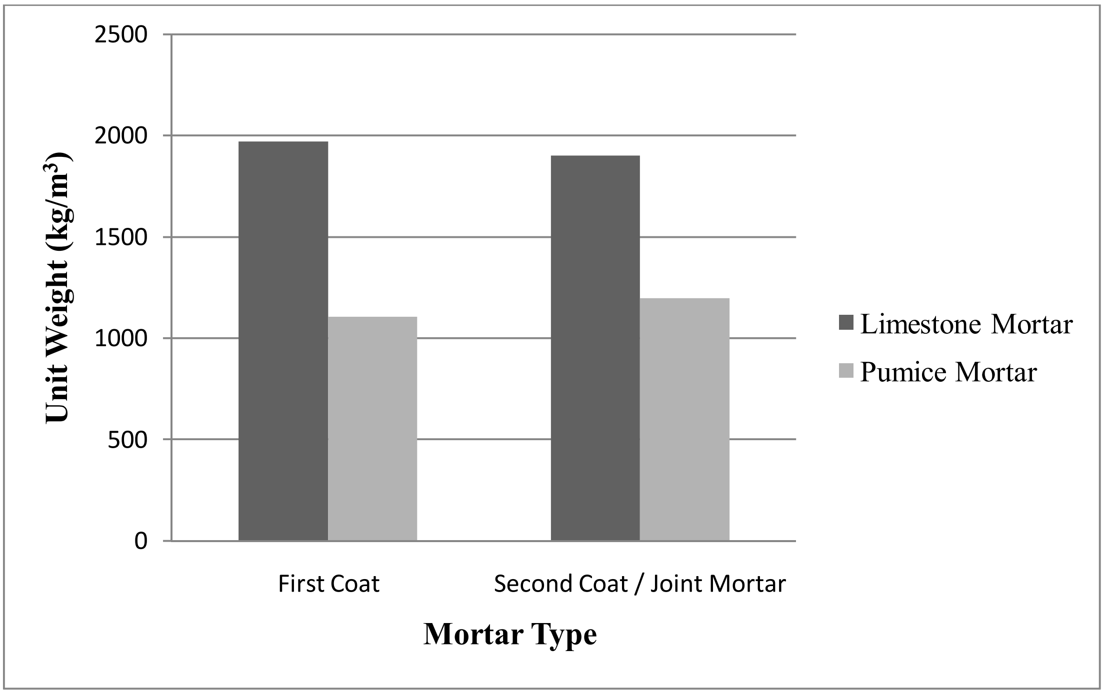


Figure 4.6: Comparasion of Hardened Unit Weight of Limestone and Pumice Mortars

4.2.5 Water Absorption Test

The results of percentage of water absorption of limestone mortars (traditional) and pumice mortars are given in Table 4.9 and Table 4.10, respectively. Figure 4.7 shows the comparasion of percentage of water absorption of mortars.

From Figure 4.7, the following can be said:

1. Percentage of water absorption of first coat and second coat plastering / joint mortars made of limestone aggregate are 4.84 % and 17.18 %, respectively.
2. Percentage of water absorption of first coat and second coat plastering / joint mortar made of pumice aggregate are 18.01 % and 25.9 %, respectively.
3. Pumice mortars has higher percentage of water absorption compared to limestone mortars for both first coat and second coat plastering / joint mortars.
4. In case of first coat plastering percentage of water absorption of pumice mortars is three times higher compared to limestone mortar.
5. For second coat plastering / joint mortar, percentage of water absorption of pumice mortars is 1.5 times higher compared to limestone mortars.

Table 4.9: Percentage of Water Absorption of Limestone Mortars

Type	No	Dry Weight (kg)	Wet Weight (kg)	Absorption (%)
First Coat	1	1.981	2.079	4.95
	2	1.948	2.051	5.29
	3	1.983	2.068	4.29
AVERAGE		1.97	2.07	**4.84**
Second Coat / joint Mortar	1	1.877	2.203	17.37
	2	1.909	2.241	17.39
	3	1.918	2.24	16.79
AVERAGE		1.9	2.23	**17.18**

Table 4.10: Percentage of Water Absoprtion of Pumice Mortars

Type	No	Dry Weight (kg)	Wet Weight (kg)	Absorption (%)
First Coat	1	1.085	1.294	19.26
	2	1.17	1.342	14.7
	3	1.067	1.281	20.06
AVERAGE		1.11	1.31	**18.01**
Second Coat / Joint Mortar	1	1.224	1.498	22.39
	2	1.187	1.47	23.84
	3	1.179	1.55	31.47
AVERAGE		1.2	1.51	**25.9**

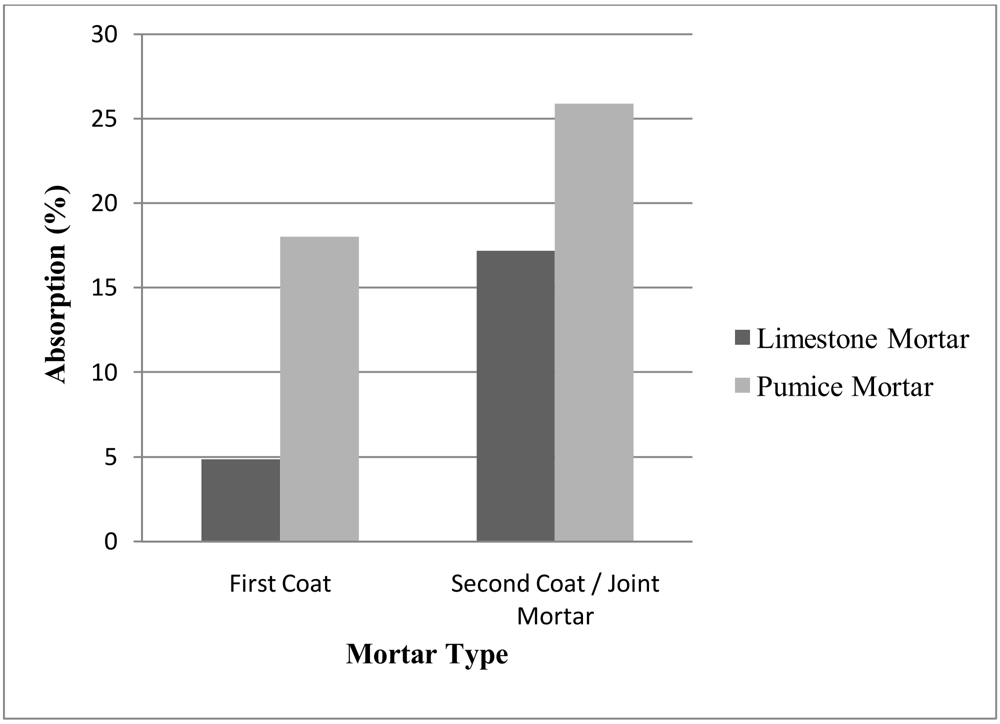


Figure 4.7: Comparasion of Percentage of Water Absorption of Limestone and Pumice Mortars

4.2.6 Coefficient of Capillary Water Absorption Test

The results of Coefficient of Capillary water absorption of limestone mortars (traditional) and pumice mortars are given in Table 4.11 and Table 4.12, respectively. Figure 4.8 shows the comparasion of coefficient of capillary water absorption of mortars.

From Figure 4.8, the following can be said:

1. Coefficient of capillary water absorption of first coat and second coat plastering / joint mortar made of limestone aggregate are 66.84 $g/m^2s^{0.5}$ and 188.42 $g/m^2s^{0.5}$ respectively.
2. Coefficient of capillary water absoprtion of first coat and second coat plastering / joint mortar made of pumice aggregate are 78.92 $g/m^2s^{0.5}$ and 226.11 $g/m^2s^{0.5}$ respectively.
3. Pumice mortars has higher coefficient of capillary water absorption compared to limestone mortars in case of both first coat and second coat plastering / joint mortar.
4. For the case of first coat plastering, coefficient of capillary water absorption of pumice mortars is 1.18 times higher compared to limestone mortar.
5. For the case of second coat plastering / joint mortar, coefficent of capillary water absorption of pumice mortars has 1.2 times higher compared to limestone mortars.

Table 4.11: Coefficient of Capillary Water Absorption of Limestone Mortar

Type	No	Dry Weight (gr)	Wet Weight (gr)	Coefficient of Capillary Water Absorption ($g/m^2s^{0.5}$)
First Coat	1	458	490	68.26
	2	451	480	61.86
	3	447	480	70.39
AVERAGE		452	483.3	**66.84**
Second Coat / Joint Mortar	1	478	568	191.98
	2	493	576	177.05
	3	499	591	196.25
AVERAGE		490	578.3	**188.42**

Table 4.12: Coefficient of Capillary Water Absorption of Pumice Mortar

Type	No	Dry Weight (gr)	Wet Weight (gr)	Coefficient of Capillary Water Absorption ($g/m^2s^{0.5}$)
First Coat	1	257	296	83.19
	2	254	291	78.92
	3	246	281	74.66
AVERAGE		252.3	289.3	**78.92**
Second Coat / Joint Mortar	1	266	367	215.44
	2	273	379	226.11
	3	278	389	236.77
AVERAGE		272.3	378.3	**226.11**

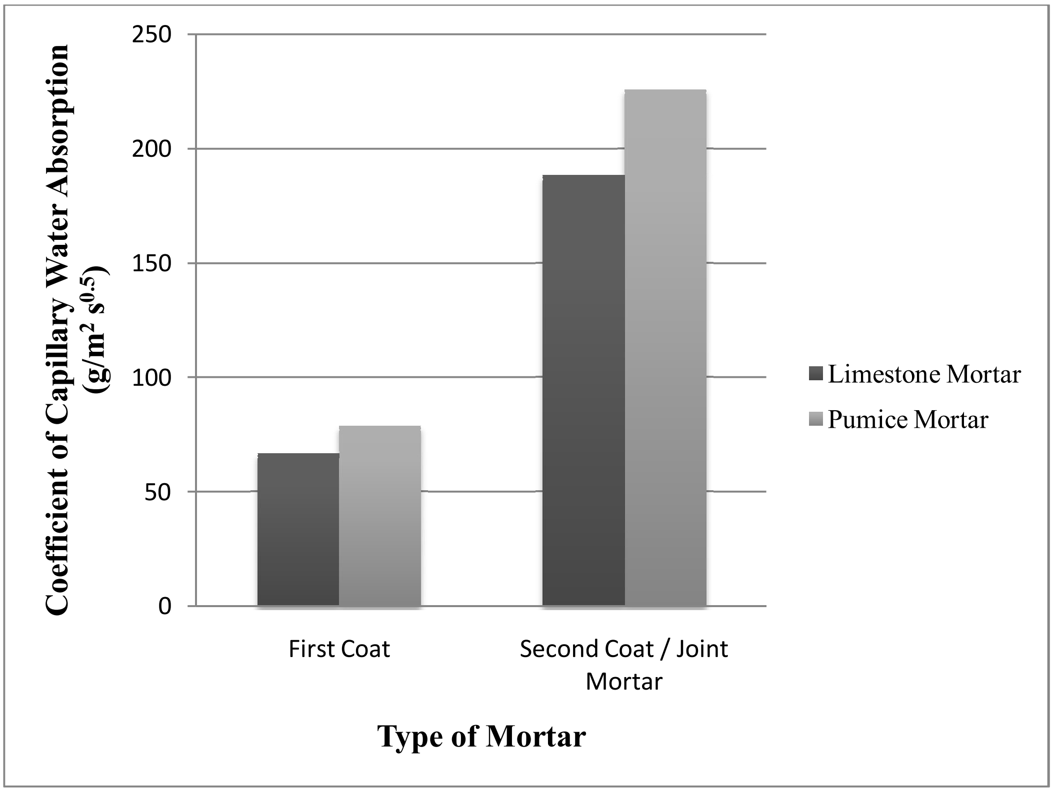


Figure 4.8: Comparasion of Coefficient of Capillary Water Absorption Capacity of Limestone and Pumice Mortars.

4.2.7 Percentage of Drying Shrinkage Test

The results of percentage of drying shrinkage of limestone mortars (traditional) and pumice mortars are given in Table 4.13 and Table 4.14, respectively. Figure 4.9 shows the comparasion of percentage of drying shrinkage of mortars.

From Figure 4.9, the following can be said:

1. The percentage of drying shrinkage of first coat and second coat plastering / joint mortar made of limestone aggregate are 0.195 % and 0.07 %, respectively.
2. The percentage of drying shrinkage of first coat and second coat plastering / joint mortar made of pumice aggregate are 0.247 % and 0.17 %, respectively.
3. Pumice mortars has higher percentage of drying shrinkage compared to limestone mortars for the case of both first coat and second coat plastering / joint mortar.
4. For the case of first coat plastering, percentage of drying shrinkage of pumice mortar is 1.27 times higher compared to limestone mortar.
5. For the case of second coat plastering / joint mortar, percentage of drying shrinkage of pumice mortar is 2.42 times higher compared to limestone mortars.

Table 4.13: Percentage of Drying Shrinkage of Limestone Mortar

Mortar Type	No	Division					Drying Shrinkage (%)
		Initial	4 days	11 days	18 days	25 days	
First Coat	1	1390	1291	1206	1154	1087	0.19
	2	1367	1213	1134	1091	1005	0.22
	3	1421	1357	1298	1231	1139	0.176
AVERAGE		1392.7	1287	1212.7	1158.7	1077	**0.195**
Second Coat /Joint Mortar	1	1105	1090	1037	994	949	0.09
	2	1237	1211	1193	1175	1132	0.065
	3	1075	1047	1011	988	965	0.068
AVERAGE		1139	1116	1080.3	1052.3	1015.3	**0.07**

Note: 1 division is equal to 0.001 mm.

Table 4.14: Percentage of Drying Shrinkage of Pumice Mortar

Mortar Type	No	Division: Initial	4 days	11 days	18 days	25 days	Drying Shrinkage (%)
First Coat	1	1298	1109	1065	997	913	0.24
	2	1393	1226	1154	1035	986	0.254
	3	1206	1032	957	903	810	0.247
AVERAGE		1299	1122.3	1058.7	978.3	903	**0.247**
Second Coat /Joint Mortar	1	1253	1245	1160	1130	1005	0.155
	2	1321	1290	1176	1109	1034	0.18
	3	1374	1312	1275	1211	1117	0.16
AVERAGE		1316	1282.3	1203.7	1150	1052	**0.17**

Note: 1 division is equal to 0.001 mm.

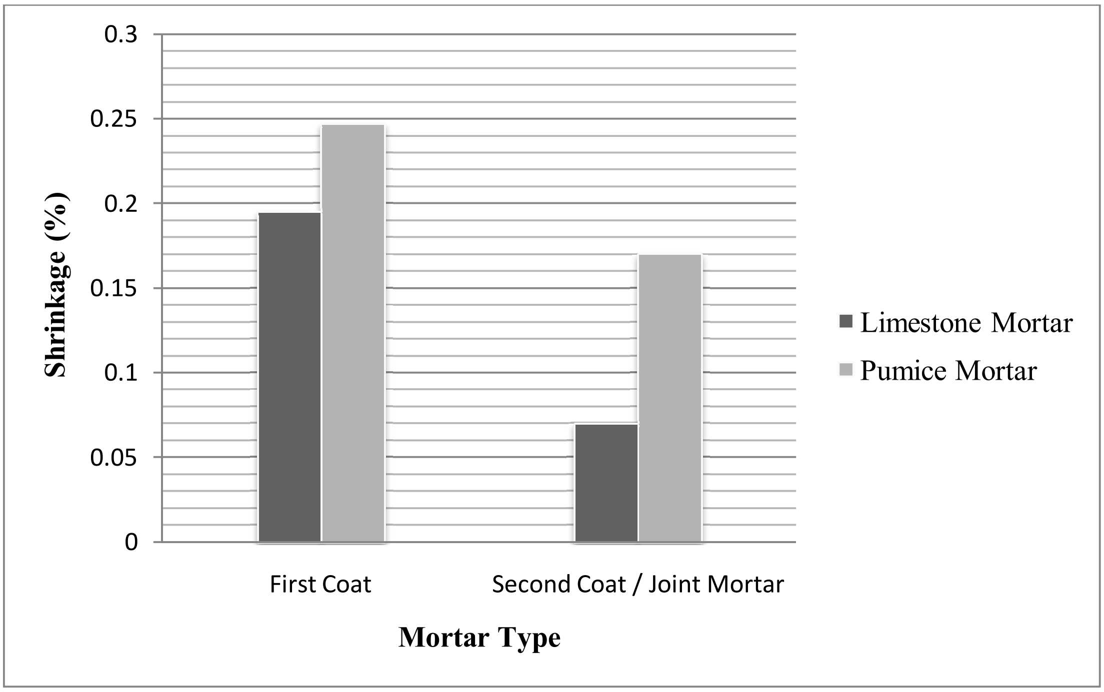


Figure 4.9: Comparasion of Percentage of Drying Shrinkage of Limestone and Pumice Mortar.

4.2.8 Flexural Strength Test

The results of flexural strength of limestone mortars (traditional) and pumice mortars are given in Table 4.15 and Table 4.16 respectively. Figure 4.10 shows the comparasion of 7 days age flexural strength of limestone and pumice mortars. Figure 4.11 shows the comparasion of 28 days age flexural strength of limestone and pumice mortars, respectively.

From Figure 4.10, the following can be said:

1- 7 days age flexural strength of first coat limestone and pumice plastering mortars are 1.40 MPa and 1.45 MPa, respectively.

2- 7 days flexural strength of second coat plastering / joint mortar limestone and pumice mortars are 0.78 MPa and 1.06 MPa, respectively.

3- Pumice mortars has higher flexural strength at 7 days age compared to limestone mortars for both first coat and second coat plastering / joint mortar.

4- For the case of first coat plastering, 7 days age flexural strength of pumice mortar is 1.04 times higher compared to limestone mortars.

5- For the of second coat plastering / joint mortar, flexural strength of pumice mortar at 7 days age is 1.36 times higher compared to limestone mortar.

6- It is observed that, lime causes a considerably decrease in flexural strength. The results indicated , the 7 days age flexural strength of first coat plastering mortars is 1.4 times higher compared to second coat plastering / joint mortar for both limestone and pumice mortars.

From Figure 4.11, the following can be said:

1- 28 days age flexural strength of first coat limestone and pumice plastering mortars are 2.78 MPa and 2.83 MPa, respectively.

2- 28 days age flexural strength of second coat limestone and pumice plastering mortars are 0.98 MPa and 1.79 MPa, respectively.

3- Flexural strength of pumice mortar is higher compared to limestone mortars for both first coat and second coat plastering mortar.

4- For the case of first coat plastering, 28 days age flexural strength of pumice mortar is 1.01 times higher compared to limestone mortar.

5- For the case of second coat plastering, 28 days age flexural strength of pumice mortar is 1.83 times higher compared to limestone mortar.

6- It is observed that, lime causes significant decrease in flexural strength. The results indicated that, 28 days age flexural strength of first coat limestone mortars is 2.83 times higher compared to second coat limestone plastering mortar. Likewise 28 days age flexural strength of first coat pumice mortar is 1.58 times higher compared to second coat pumice plastering mortar.

Table 4.15: Flexural Strength Results of Limestone Mortars.

		7 Days Age		28 Days Age	
Type	**No**	**Failure Load (N)**	**Flexural Strenght (MPa)**	**Failure Load (N)**	**Flexural Strenght (MPa)**
First Coat	1	899	1.40	1782	2.78
	2	921	1.44	1767	2.76
	3	877	1.37	1794	2.80
AVERAGE		899	**1.40**	1781	**2.78**
Second Coat / Joint Mortar	1	350	0.55	640	1.00
	2	560	0.88	623	0.97
	3	578	0.90	611	0.95
AVERAGE		496	**0.78**	625	**0.98**

Table 4.16: Flexural Strength Results of Pumice Mortars.

		7 Days Age		28 Days Age	
Type	**No**	**Failure Load (N)**	**Flexural Strenght (MPa)**	**Failure Load (N)**	**Flexural Strenght (MPa)**
First Coat	1	916	1.43	1798	2.81
	2	934	1.46	1816	2.84
	3	931	1.45	1827	2.85
AVERAGE		927	**1.45**	1814	**2.83**
Second Coat / Joint Mortar	1	690	1.08	1170	1.83
	2	663	1.04	1141	1.78
	3	679	1.06	1127	1.76
AVERAGE		677	**1.06**	1146	**1.79**

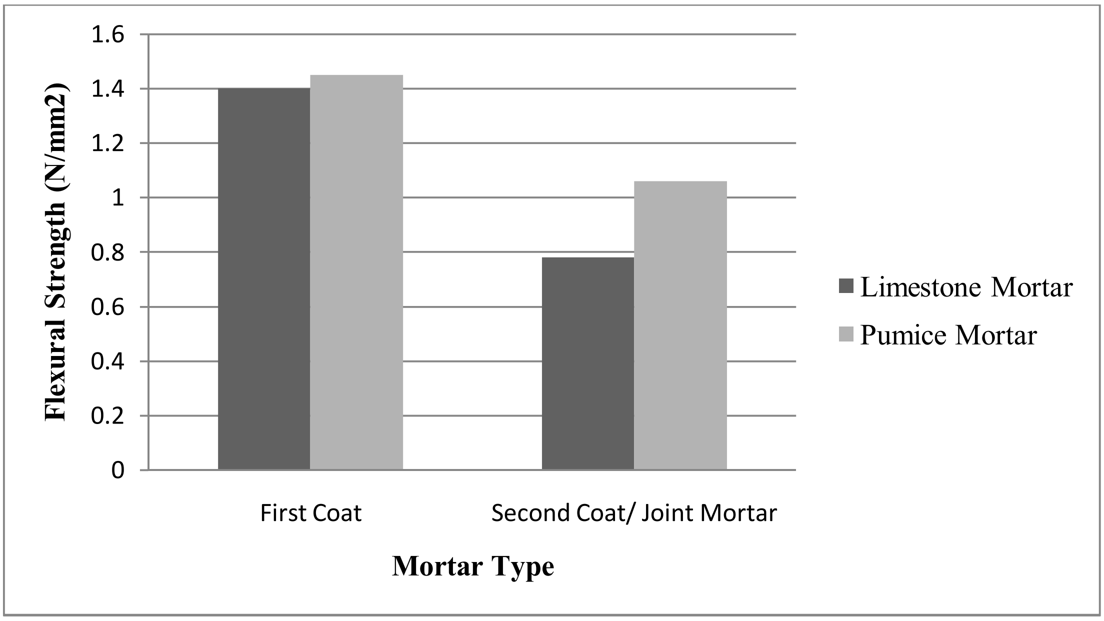


Figure 4.10: Comparasion of 7 Days Age Flexural Strength of Limestone and Pumice Mortar.

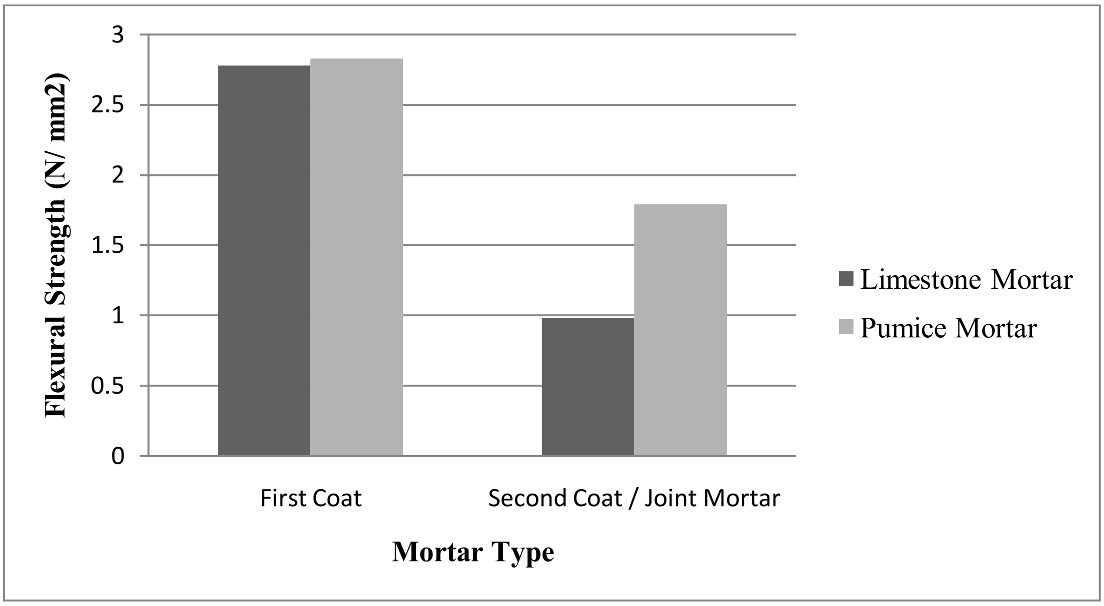


Figure 4.11: Comparasion of 28 Days Age Flexural Strength of Limestone and Pumice Mortars.

4.2.9 Compressive Strength Test

The results of compressive strength of limestone mortars and pumice mortars are given in Table 4.17 and Table 4.18, respectively. Figure 4.12 shows the comparasion of 7 days age compressive strength of limestone and pumice mortars. Figure 4.13 shows the comparasion of 28 days age compressive strength of limestone and pumice mortars respectively.

From Figure 4.12, the following can be said:

1- 7 days age compressive strength of first coat limestone and pumice plastering mortars are 6.02 MPa and 6.55 MPa, respectively.

2- 7 days age compressive strength of second coat limestone and pumice mortars are 2.15 MPa and 3.21 MPa, respectively.

3- 7 days age compressive strength of pumice mortar is higher compared to limestone mortar for both first coat and second coat plastering.

4- 7 days age compressive strength of first coat pumice plastering mortar is 1.1 times higher compared to limestone mortar.

5- 7 days age compressive strength of second coat pumice plastering mortar is 1.5 times higher compared to limestone mortars.

6- It is observed, lime causes considerably decrease in compressive strength. The results indicates compressive strength of first coat plastering mortars is 2.5 times higher compared to second coat plastering mortars for both limestone and pumice mortars.

From Figure 4.13, the following can be said:

1- 28 days age compressive strength of first coat limestone and pumice plastering mortars are 8.92 MPa and 9.48 MPa, respectively.
2- 28 days age compressive strength of second coat limestone and pumice mortars are 2.83 MPa and 5.20 MPa, respectively.
3- 28 days age compressive strength of pumice mortar has higher compared to limestone mortar for both first coat and second coat plastering.
4- 28 days age compressive strength of first coat pumice plastering mortar is 1.06 times higher compared to limestone mortar.
5- 28 days age compressive strength of second coat pumice plastering mortar is 1.85 times higher compared to limestone mortars.
6- It is observed that, lime causes significant decrease in compressive strength. The results indicated that, compressive strength of first coat limestone mortars is 3.15 times higher compared to second coat limestone plastering mortars. Likewise compressive strength of first coat limestone plastering mortar is 1.82 times higher compared to second coat pumice plastering mortar.

Table 4.17: Compressive Stregth Results of Limestone Mortars.

Type	No	7 Days Age		28 Days Age	
		Failure Load (N)	**Compressive Strength (MPa)**	**Failure Load (N)**	**Compressive Strength (MPa)**
First Coat	1	9470	5.92	14608	9.13
	2	9450	5.91	14078	8.80
	3	9972	6.23	14123	8.83
AVERAGE		9631	**6.02**	14270	**8.92**
Second Coat / Joint Mortar	1	2990	1.87	4460	2.79
	2	3920	2.45	4590	2.87
	3	3430	2.14	4530	2.83
AVERAGE		3447	**2.15**	4527	**2.83**

Table 4.18: Compressive Strength Results of Pumice Mortar

Type	No	7 Days Age		28 Days Age	
		Failure Load (N)	**Compressive Strength (MPa)**	**Failure Load (N)**	**Compressive Strength (MPa)**
First Coat	1	10128	6.33	15280	9.55
	2	10543	6.59	15352	9.60
	3	10789	6.74	14875	9.30
AVERAGE		10487	**6.55**	15169	**9.48**
Second Coat / Joint Mortar	1	4220	2.64	8060	5.04
	2	5530	3.46	8780	5.49
	3	5680	3.55	8100	5.06
AVERAGE		5143	**3.21**	8313	**5.20**

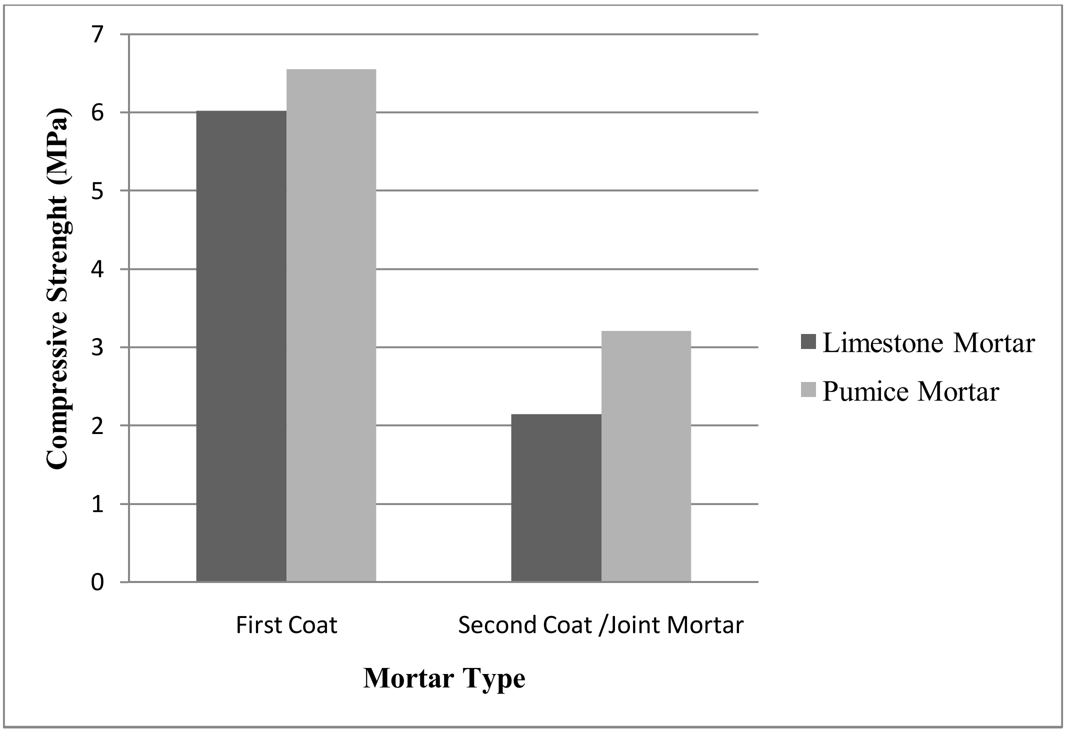


Figure 4.12: Comparasion of 7 Days Age Compressive Strength of Limestone and Pumice Mortars.

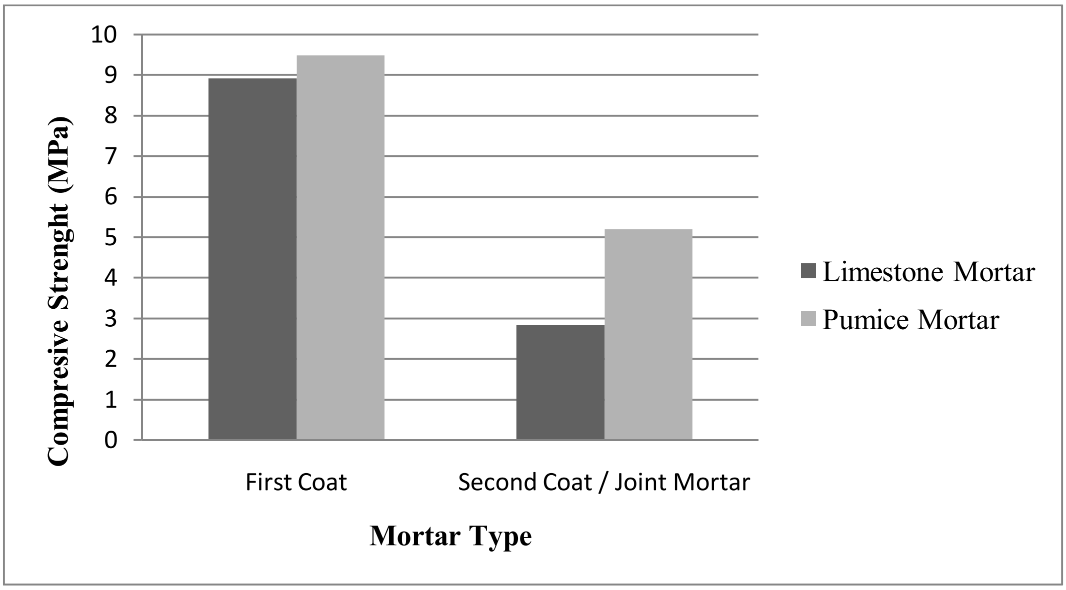


Figure 4.13: Comparasion of 28 Days Age Compressive Strength of Limestone and Pumice Mortars

4.2.10 Ultrasonic Pulse Velocity Test

The results of ultrasonic pulse velocity of limestone mortars and pumice mortars are given in Table 4.19 and Table 4.20, respectively. Figure 4.14 shows the comparasion of ultrasonic pulse velocities of limestone and pumice mortars.

From Figure 4.14, the followings can be said:

1- The ultrasonic pulse velocities of first coat and second coat plastering / joint mortars made of limestone aggregate are 3.32 km/s and 2.51 km/s, respectively.

2- The ultrasonic pulse velocities of first coat and second coat plastering/ joint mortar made of pumice aggregate are 2.89 km/s and 2.40 km/s, respectively.

3- Ultrasonic pulse velocities of limestone mortars is higher compared to pumice mortars for both first coat and second coat plastering.

4- Ultrasonic pulse velocity is directly related to density of material. Higher density results higher ultrasonic pulse velocity. Therefore higher ultrasonic pulse velocity indicates higher density and less voids in materials. Ultrasonic pulse velocity of limestone mortar is 1.1 times higher compared to pumice mortar due to difference in unit weight of aggregates.

5- Lime causes reduction in ultrasonic pulse velocity. It is observed that, first coat plastering mortar is 1.3 times higher compared to second coat plastering mortars for both limestone and pumice mortars.

Table 4.19: Ultrasonic Pulse Velocities of Limestone Mortars.

Mortar Type	**No**	**Transmit Time (msec)**	**Velocity (km/s)**
First Coat	1	30.3	3.3
	2	30.7	3.26
	3	29.5	3.39
AVERAGE		30.2	**3.32**
Second Coat / Joint Mortar	1	39.5	2.53
	2	39.8	2.51
	3	40.2	2.49
AVERAGE		39.8	**2.51**

Table 4.20: Ultrasonic Pulse Velocities of Pumice Mortars.

Mortar Type	**No**	**Transmit Time (msec)**	**Velocity (km/s)**
First Coat	1	33.6	2.98
	2	35.4	2.82
	3	34.9	2.87
AVERAGE		34.6	**2.89**
Second Coat/ Joint Mortar	1	41.2	2.43
	2	41.7	2.4
	3	41.9	2.39
AVERAGE		41.6	**2.4**

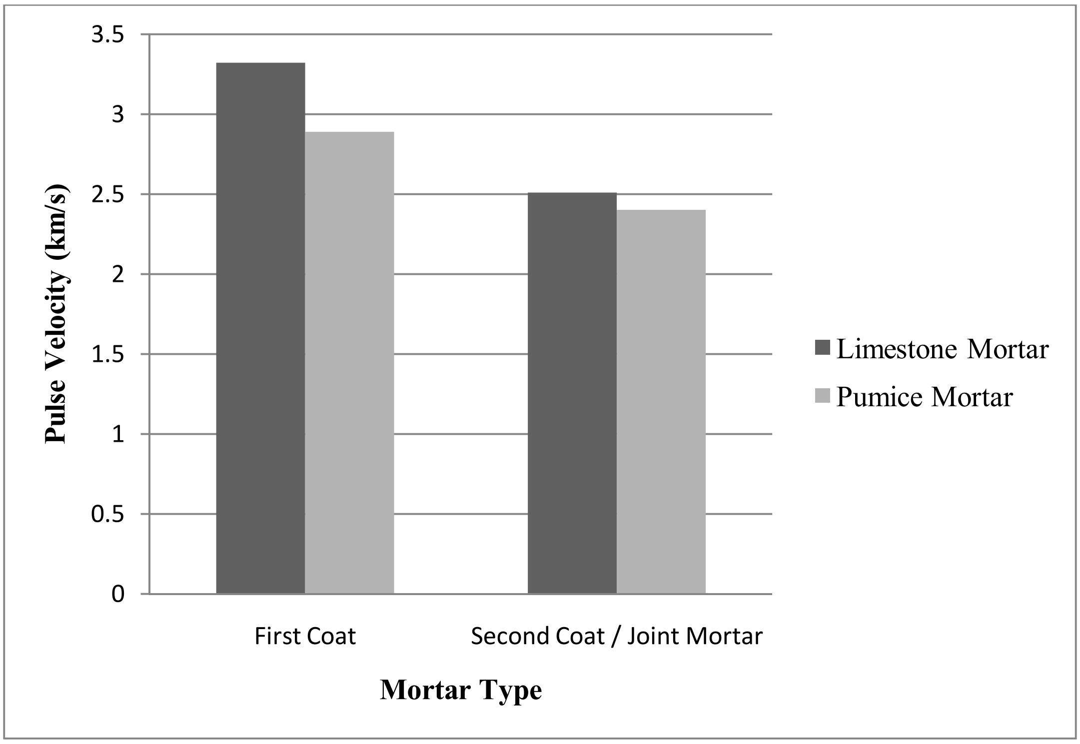


Figure 4.14 : Comparasion of Ultrasonic Pulse Velocities of Limestone and Pumice Mortars.

4.2.11 Coefficient of Thermal Conductivity of Wall Systems

The coefficient of thermal conductivity is a measure of a amount of heat (energy) passing perpendicularly through a 1m^2 area of homogeneous material of 1 meter thickness for a temperature difference between two surface of a one degree during 1 hour; 'λ' is expressed as 'W/mK'.The results of coefficient of thermal conductivity of wall systems made with pumice and limestone mortar / plaster (traditional) as well as different type of masonry units are shown in Table 4.21, 4.22 and 4.23 respectively. Figure 4.15 shows the comparasion of thermal condcutivity coefficient of wall systems individually made with pumice mortar / plaster and limestone mortar / plaster as well as clay brick wall system. Figure 4.16 shows the comparasion of thermal conductivity coefficient of wall systems versus net unit weight and hollow file number of masonry units used in walls. Figure 4.17 shows the schematic presentation of path way of heat flow through 2 and 3 file hollow pumice blocks.

From Figure 4.15, the followings can be said:

1. Coefficient of thermal conductivity of type 1, 2, and 3 pumice block wall systems with limestone mortar / plaster are 0.3021 W/mK, 0.2655 W/mK and 0.2422 W/mK, respectively.
2. Coefficient of thermal condcutivity of type 1, 2, and 3 pumice block wall systems with pumice mortar / plaster are 0.2647 W/mK, 0.2219 W/mK and 0.2084 W/mK, respectively.
3. Coefficient of thermal condcutivity of clay brick wall system with limestone mortar/plaster is 0.4156W/mK .

4. The coefficient of thermal conductivity of pumice block wall systems made with pumice mortar / plaster are lower compared to pumice block wall systems made with limestone mortar / plaster.
5. Coefficient of thermal conductivity of pumice block wall systems made with limestone mortar / plaster is 1.2 times higher compared to pumice block wall systems made with pumice mortar / plaster.
6. Coefficient of thermal conductivity of clay brick wall system is 1.7 and 2.0 times higher compared to pumice block wall systems made with limestone mortar / plaster and pumice mortar / plaster, respectively.
7. It is observed that use of pumice mortar / plaster in wall systems instead of limestone mortar / plaster provides about 16 % extra thermal insulation in walls. Unit weight of limestone mortar is 1.7 times higher compared to pumice mortars. In general, the most important influencing factor on thermal insulation capacity is the reduced unit weight of the material. This is because the lighter material provides better heat insulating characteristics. Lower unit weight of material resulted lower coefficent of thermal conductivity which means better heat insulation performance. It is known that denser materials (higher density) conduct heat faster than the looser material (lower density). Next figure shows the effect of unit weight of masonry units based on thermal condcutivity coefficient of wall systems.
8. Coefficent of thermal conductivity is the most important property of the material that can describe the performance of the material based on thermal insulation. Generally thermal insulation is defined as the resistance of material that reduces heat flow within material. Lower coefficient of thermal condcutivity indicated higher thermal insulation of material. For instance, if

any material has zero coefficent of thermal conductivity means no heat flow through the material.

From Figure 4.16 and 4.17, the following can be said:

1. In general, the most important influencing factor on thermal insulation capacity is the unit weight of the material. This is because the lighter material provides better heat insulating characteristics. The unit weight of the concrete is influenced by the density of the aggregate and its particle size distribution.
2. Coefficent of thermal conductivity increases with incresing unit weight of masonry units. Therefore there is a direct relation between unit weight and coefficent of thermal condcutivity of material.
3. Thermal conductivity coefficent of wall systems made with pumice mortar / plaster and pumice block with unit weights of 675 kg/m^3, 712 kg/m^3, and 740 kg/m^3 are 0.2084 W/mK, 0.2219 W/mK and 0.2647 W/mK, respectively.
4. Thermal condcutivity coefficent of wall systems made with limestone mortar / plaster and pumice block with unit weights 675kg/m^3, 712 kg/m^3, and 740kg/m^3 are 0.2484 W/mK, 0.2655 W/mK and 0.3021 W/mK, respectively.
5. Coefficent of thermal condcutivity of wall systems made with limestone mortar / plaster and clay brick with unit weight of 1100 kg/m^3 is 0.4156 W/mK.
6. There is a direct relation between proportion of the solid surface area and net unit weight of pumice block. Net unit weight is decreasing with decreasing proportion of solid surface area of pumice block.
7. The other important influencing factor is geometry of pumice block. Coefficent of thermal conductivity decreases with increasing hollow file

number of pumice block (Figure 4.17). Therefore, longer distance of path way of heat flow results lower coefficent of thermal conductivity which means better heat insulating performance. The results indicated that, coefficient of thermal condcutivity of wall systems made with 2 file hollow pumice block is about 1.2 times higher compared to wall system made with 3 file hollow pumice block. Therefore increasing the number of hollow file in pumice block provides better heat insulation performance of the wall.

8. Coefficent of thermal conductivity of clay brick wall system is about 1.7 and 2.0 times higher compared to pumice block wall system made with limestone and pumice mortar / plaster, respectively. Therefore thermal condcutivity coefficent of clay brick wall system is significantly higher compared to pumice blcok wall system. The most influencing factor is the higher unit weight of clay brick. Unit weight of clay brick is about 1.6 times higher compared to pumice blocks. Therefore this factor is reflected the results of thermal condcutivity coefficent of clay brick wall systems.

Table 4.21: Coefficent of Thermal Conductivty of Wall Systems Made with Pumice Mortar / Plaster and Pumice Block.

Wall Type No	**Type of Mortar / Plaster**	**Dimensions of Pumice Block (t x Lx h), mm**	**Number of Hollow File of Pumice Block**	**Proportion of Solid Surface Area of Pumice Block (%)**	**Unit Weight of Pumice Block (kg/m^3)**	**Coefficient of Thermal Conductivity (λ), W/mK**
1	Pumice	150 x 390 x 185	2	65	740	0.2647
2	Pumice	190 x 390 x 185	3	62	712	0.2219
3	Pumice	250 x 390 x 185	3	58	675	0.2084

Table 4.22: Coefficent of Thermal Conductivity of Wall Systems Made with Limestone Mortar / Plaster and Pumice Block.

Wall Type No	**Type of Mortar / Plaster**	**Dimensions of Pumice Block (t x L x h), mm**	**Number of HollowFile of Pumice Block**	**Proportion of Solid Surface Area of Pumice Block (%)**	**Unit Weight of Pumice Block (kg/m^3)**	**Coefficient of Thermal Conductivity (λ), W/mK**
4	Limestone	150 x 390 x 185	2	65	740	0.3021
5	Limestone	190 x 390 x 185	3	62	712	0.2655
6	Limestone	250 x 390 x 185	3	58	675	0.2422

Table 4.23: Coefficent of Thermal Conductivity of Clay Brick Wall System.

Wall Type No	**Type of Mortar / Plaster**	**Dimensions of Clay Brick (t x L x h), mm**	**Number of Holes of Clay Brick**	**Unit Weight of Clay Brick (kg/m^3)**	**Coefficient of Thermal Conductivity (λ), W/mK**
7	Limestone	200 x 300 x 100	8	1100	0.4156

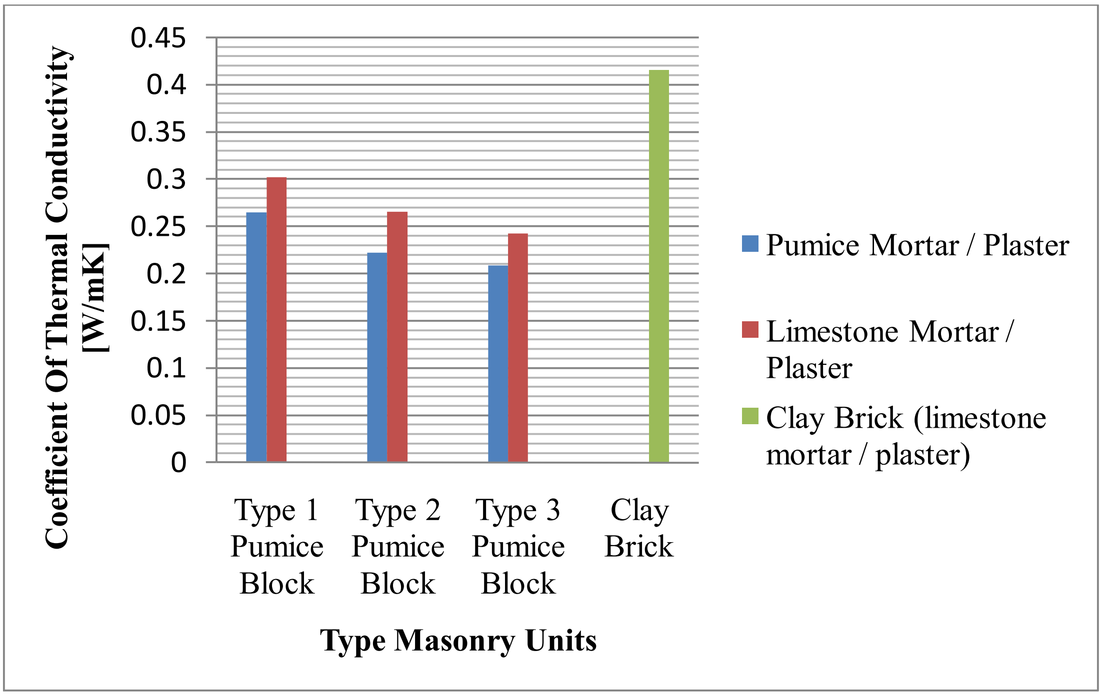


Figure 4.15: Comparasion of Thermal Conductivity Coefficent of Wall Systems Made with Pumice and Limestone Mortar / Plaster

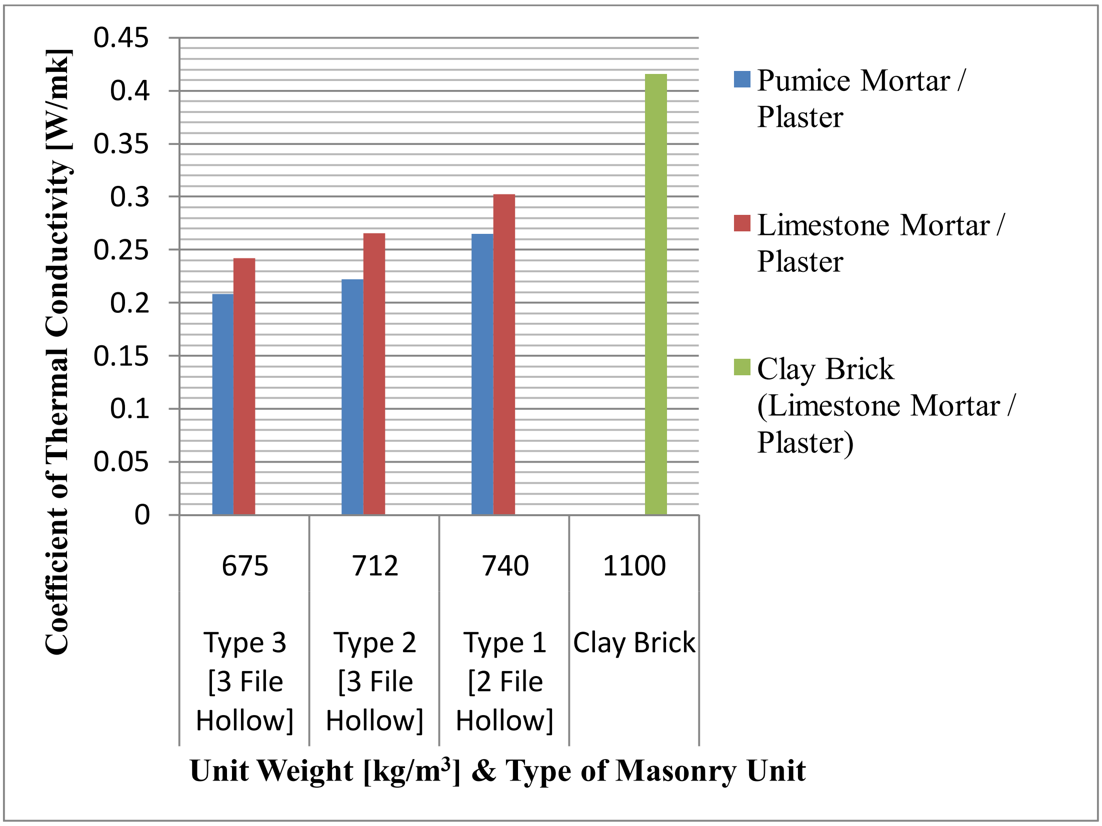
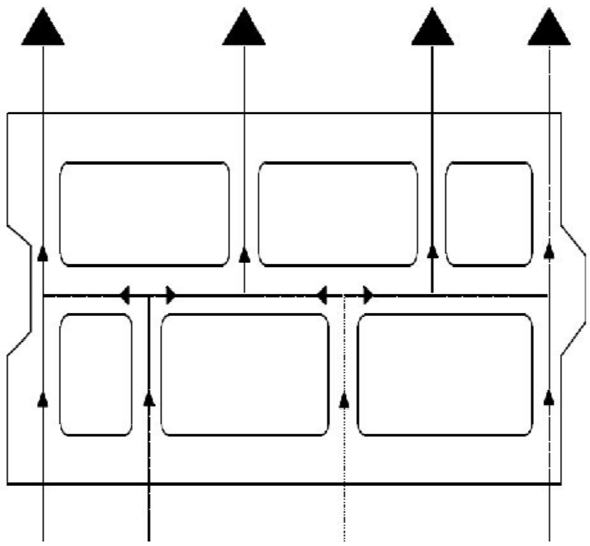
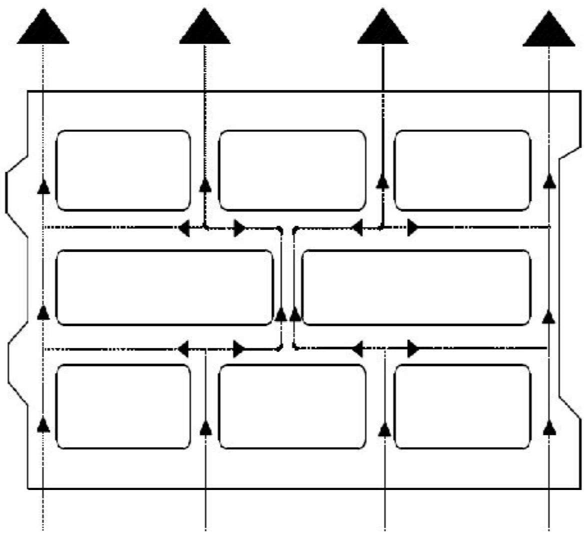


Figure 4.16: Comparasion of Thermal Conductivity Coeffient of Wall Systems with respect to Unit Weight and Hollow Number of Masonry Units Used in Walls.



(a) Path Way of Heat Flow Within 2 File Hollow Pumice Block



(b) Path Way of Heat Flow Within 3 File Hollow Pumice Block

Figure 4.17: Schematic Presentation of Path Way of Heat Flow Through 2 File and 3 File Hollow Pumice Blocks.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The experimental research findings showed that, the properties of pumice mortars which indicate lower value compared to limestone mortars are; workability duration, time of settings, fresh unit weight, hardened unit weight, and ultrasonic pulse velocity. Properties of pumice mortars which indicate higher value compared to limestone mortars are; percentage of water absorption, coefficient of capillary water absorption, percentage of drying shrinkage, flexural strength and compressive strength. Experimental findings also showed that wall systems made with pumice mortar / plaster have a lower coefficient of thermal conductivity compared to wall systems made with limestone mortar / plaster. Additionally basic cost analysis was done and compared for mortar made of limestone and pumice aggregate and basic technical advantages of mortars were discussed in this chapter. Lastly recommendations for further research related with this thesis are also explained in this chapter.

5.2 Conclusions

5.2.1 Consistency of Fresh Mortar

Workability duration of limestone mortar is higher compared to pumice mortars in case of both first coat and second coat plastering/ joint mortar. Therefore, service duration of pumice mortars are lower compared to limestone mortar due to higher rate of stiffening.

5.2.2 Time of Settings

Setting times of limestone mortars are higher compared to pumice mortars in case of both initial and final setting times. In fact, time of settings are directly depends on the workability duration of mortars. This means, higher time of settings resulted higher workability duration of mortars. The research findings shows, there is direct relation between workability duration and setting times of mortars.

5.2.3 Fresh Unit Weight

Fresh unit weight of limestone mortars are higher compared to pumice mortars in case of both first coat and second coat plastering/ joint mortars. This means, mortars made of limestone aggregate is heavier per unit volume compared to mortars made of pumice aggregate. It is clear, properties of aggregates are directly effects the unit weight of mortars. Therefore, use of pumice mortars and plaster in wall construction will cause obvious reduction of dead load of building.

5.2.4 Hardened Unit Weight

Hardened unit weight of limestone mortars are higher compared to pumice mortars in case of both first coat and second coat plastering / joint mortar. This means, limestone mortars are heavier per unit volume compared to pumice mortars due to properties of aggregates. Therefore, use of pumice mortar and plaster in wall construction will cause obvious reduction in dead load of building.

5.2.5 Water Absorption Capacity

Percentage of water absorption of pumice mortars are higher compared to limestone mortars in case of both first coat and second coat plastering / joint mortar. Findings shows water absorption capacity of pumice mortars are considerably higher compared to limestone mortars due to properties of aggregates. As it is well known, pumice aggregates consists up to 80% air voids. For this reason percentage of water absorption of pumice aggregate is about 10 times higher compared to limestone aggregate used in this investigation. Therefore use of saturated pumice aggregate will reduce the water absorption capacity of mortars.

5.2.6 Coefficient of Capillary Water Absorption

Coefficient of capillary water absorption of pumice mortars are higher compared to limestone mortars in case of both first coat and second coat plastering / joint mortar. There is a direct relation between capillarity and porosity of the construction materials. Because highly prone to water absorption and more water passage channels are available in higher porous materials. Therefore use of saturated pumice aggregate will be resulted in reduction of coefficient of capillary water absorption of pumice mortars.

5.2.7 Percentage of Drying Shrinkage

Percentage of drying shrinkage of pumice mortars are higher compared to limestone mortars. Drying shrinkage of mortars is caused by the loss of water in drying process which results decrease in volume (contraction) of mortars. Drying shrinkage is directly proportional to the water / cement ratio. When a hardened mortar, cured in water , is allowed to dry it first loses water from its voids and pores and starts to shrink during further drying. Therefore, voids and pores are filled full of water in pumice aggregates causes more water is contained in pumice mortars which results higher loss of water during drying. This causes more decrease in volume (contraction) in pumice mortar. It can be understood from the result that the risk of shrinkage cracking is higher in pumice mortar / plaster compared to limestone mortar / plaster. Threfore lower shrinkage behavior is desirable in mortar / plaster for reduction of the risk of shrinkage cracking. Additionally percentage of drying shrinkage of first coat plastering is higher compared to second coat plastering due to higher water content of first coat plastering.

5.2.8 Flexural Strength

Flexural strength (at 7 and 28 days age) of pumice mortars are higher compared to limestone mortars in case of both first coat and second coat plastering / joint mortar. As it is well known, pumice is a pozzolanic material. Pozzolans are siliceous and alumni-siliceous volcanic tuffs. When they are alone, they do not show hydraulic characteristic. They are natural materials that present their hydraulic bonding characteristic by chemical reaction with calcium hydroxide at a normal temperature when ground very fine in wet condition. Use of pumice in concrete or mortar can serve as a pozzolan. Especially, powder pumice aggregates (very fine particles) shall serve as a pozzolan in an active way when attending to the mortar. Therefore very fine pumice aggregates provides serious advantages for strength gain and durability of the mix.

5.2.9 Compressive Strength

Compressive strength (at 7 and 28 days age) of pumice mortars are higher compared to limestone mortars in case of both first coat and second coat plastering / joint mortar. This is due to highly pozzolanic activity of pumice aggregates. Use of powder pumice aggregate (very fine paticles) in mortars causes higher strength gain of the mix.

5.2.10 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity of limestone mortars are higher compared to pumice mortars. This is due to density of the material. Higher density means higher ultrasonic pulse velocity. Therefore there is a direct relation between density and ultrasonic pulse velocity of mortars.

5.2.11 Coefficient of Thermal Conductivity of Wall Systems

The experimental research findings showed, coefficient of thermal conductivity of wall systems made with pumice mortar / plaster are lower compared to wall systems made with limestone mortar / plaster. In general the most important influencing factor on thermal insulation capacity is the unit weight of the material. This is because lighter material provides better heat insulating characteristics. Lower unit weight of material results lower coefficent of thermal conductivity which means beter heat insulation performance. Furthermore the thermal insulation property of pumice block wall systems is closely related to the block geometry and the characteristic properties of pumice, too. Besides, the quality of mortar and plaster used in wall construction could supply considerably benefit to heat insulation properties of pumice block wall systems.

Experimental research findings also showed that there is a considerably difference between pumice block wall system and traditional clay brick wall system based on thermal condcutivity coefficient. Clay brick wall system has about 1.5 times higher compared to pumice block wall systems in point of thermal conductivity coefficent. Therefore experimental results showed that pumice-block wall systems provides better heat insulation performance compared to wall system made with traditional clay brick.

In residential buildings, use of pumice-block instead of traditional materials (clay brick) provides about 35 – 45 % energy saving for purpose of heating and cooling. The thermal insulation property of pumice blocks is closely related to the block geometry and characteristic properties of pumice, too. It is observed that, 3 file hollow type pumice-blocks shows better heat insulation performance compared to 2 file hollow type of pumice-blocks. Therefore in geometrical design, increasing the number of hollow files in pumice-block provides beter heat insulation properties in wall systems.

Furthermore, use of pumice mortar / plaster instead of limestone mortar / plaster (traditional) in pumice-block wall systems provides about 16 % extra contribution in point of thermal insulation performance of the wall.

5.3 Basic Cost Analysis among Pumice and Limestone Mortar

Table 4.24 below shows the basic cost analysis for mortar made of pumice and limestone aggregates for 1 m^2 wall construction.

Table 5.1: Basic Cost Analysis for Pumice and Limestone Mortar

	Aggregate Type	**Pumice**	**Limestone**
	Aggregate Unit Price (TL/ton)	85	30
First Coat Plastering	Amount of Aggregate (kg/m^2)	4	10
	Cost of aggregate (TL/m^2)	0.34	0.3
	Cost (TL/m^2)	6.8	6
Second Coat Plastering/ Joint Mortar	Amount of Aggregate (kg/m^2)	16	40
	Cost of aggregate (TL/m^2)	1.36	1.2
	Cost (TL/m^2)	25	22
	Total Cost (TL/m^2)	31.8	28

In wall construction for 1 m^2 area, use of mortar and plaster made of pumice aggregate would be 12 % more expensive compared to limestone mortar / plaster (traditional). However it can be seen from results that wall systems formed by pumice mortar / plaster provides about 16 % higher thermal insulation performance compared to wall systems formed by limestone mortar / plaster. This indicates that, initial cost of pumice mortar is higher compared to limestone mortar, however higher thermal insulation performance will be achieved by use of pumice mortar / plaster. Therefore less energy will be consumed and more energy saving will be ensured over time. Additionally other important technical advantage is less unit weight of pumice mortar. Mortar / plaster made of limestone aggregate is about 1.65 times higher compared to mortar / plaster made of pumice aggregate. This indicates that limestone mortars are heavier per unit volume compared to pumice mortars due to properties of aggregates. Therefore, use of pumice mortar and plaster in wall construction will cause significant reduction in dead load of building.

According to results of this study, lightweight pumice mortar / plaster can be used in construction to obtain high thermal insulation and reduce self-weight or dead load of construction.

5.4 Recommendations

Following recommendation for further research could be done:

1. Lightweight concrete could be developed to be used for structural elements. The need arises to analyse the lightweight concrete to be used in structural elements experimentally in detail. The lightweight concrete should have specific characteristics to meet the strength and performance requirements for the application in structural elements. Thus, naturally, before recommending lightweight concrete for a structural application there is a need to study the mechanical characteristics to establish its suitability.
2. Different construction materials could be developed for manufacturing with pumice aggregate in different application areas to achieve optimum performance in terms of insulation and lightweight characteristics.
3. The properties and performances of other natural lightweight aggregate could be investigated to be used for mortar and building block production. Diatomite and volcanic slag aggregates are the other two popular and alternative natural volcanic aggregates to be used in construction materials.
4. Performance of fire resistance could be investigated on wall systems developed and tested in this thesis.
5. Sound insulation (acoustic) performance could be investigated on wall systems tested in this thesis. Because sound insulation performance is as important as heat insulation performance for human life in terms of comfortable life.

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