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Improving Energy Saving in Buildings by Enhancing Concrete Thermal Insulation Characteristics Using Mineral Additives

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Thesis submitted in partial fulfillment of requirements of the degree

Master of Science in Renewable Energy & Sustainability

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	JAMILA	

The undersigned hereby certify that they have read, examined and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University and the Faculty of Science at Al-Qdus University the approval of a thesis entitled:

Improving Energy Saving in Buildings by Enhancing Concrete Thermal Insulation Characteristics Using Mineral Additives

Submitted by

Baraa A. Y. Abu-Znaid.

in partial fulfillment of the requirements for the degree of Master in Renewable Energy & Sustainability .

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ABSTRACT

Renewable energy and sustainability involve ways to save energy consumption. One of the most important ways is to increase thermal insulation in buildings by reducing thermal conductivity of building materials such as concrete. This can be achieved by adding suitable additives to the concrete mix. Many researchers have investigated such a trend in recent years. This subject has taken on a broad importance with the increasing importance of energy saving. However, still there are gabs in published research works in issues related to the effect of enhancing thermal characteristics of concrete through the addition of various mineral additives.

In this thesis, a standard concrete mix design was modified by adding kaolin, aluminum oxide, chromium oxide or ceramic waste particles as a partial replacement of cement. Then, the effects of varying the percentage addition (5, 10, 15 and 20%) of such additives on concrete thermal characteristics were investigated. These included thermal conductivity, specific heat and thermal diffusivity. In addition, the curing progress of fresh concrete was investigating by measuring the compressive strength as a function of time until 28 days. Then, the effects of these changes on the other physical and mechanical characteristics were investigated. These included workability of fresh concrete and compressive strength, density, water absorption of fully cured concrete. The independent variables of this experimental study included additive type, addition percentage, curing time. In addition, an energy consumption model in buildings was developed to investigate the level of economic savings utilizing such enhanced concrete.

The findings indicate that increasing the percentage addition of ceramic particles or chromium oxide decreases the thermal conductivity of the concrete. This is associated with a limited decrease in the compressive strength. Similarly, increasing the percentage addition of kaolin decreases the thermal conductivity up to 10% percentage addition. However, with high percentage additions (15 and 20%), the thermal conductivity is increased. On the other hand, increasing the percentage addition of aluminum oxide increases the thermal conductivity of the concrete. The impacts of these additions on workability, water absorption and the development of compressive strength are presented. The model calculations indicate that a saving of about 8% of energy used for heating and cooling can be achieved when ceramic waste particles are used at 20% percentage addition, as a replacement of cement, for concrete of walls for a particular residential building.

Keywords: concrete, thermal insulation, conductivity, kaolin, aluminum oxide, chromium oxide, ceramic particles.

تحسين توفير الطاقة في المباني من خلال تعزيز خصائص العزل الحراري الخرساني باستخدام الإضافات المعدنية

بواسطة

براء عبد الحميد يوسف أبو زنيد.

الملخص

الطاقة المتجددة والاستدامة تتضمن طرق لتوفير استهلاك الطاقة. واحدة من أهم هذه الطرق هي زيادة العزل الحراري في المباني عن طريق تقليل الموصلية الحرارية لمواد البناء مثل الخرسانة. يمكن تحقيق ذلك عن طريق إضافة إضافات مناسبة إلى مزيج الخرسانة. لقد حقق العديد من الباحثين في مثل هذا الاتجاه البحثي في السنوات الأخيرة. اكتسب هذا الموضوع أهمية واسعة مع الأهمية المتزايدة لتوفير الطاقة. ومع ذلك، لا يزال هناك نقص في الأعمال البحثية المنشورة في القضايا المتعلقة بتحسين الخصائص الحرارية للخرسانة من خلال إضافة الإضافات المعدنية لخليط الخرسانة.

في هذه الأطروحة، تم تعديل تصميم مزيج الخرسانة القياسي بإضافة جزيئات الكولين أو أكسيد الألومنيوم أو أكسيد الكروم أو نفايات السيراميك كبديل جزئي للإسمنت. تم دراسة تأثير تغير نسبة الإضافة (5 و10 و15 و20٪) من هذه الإضافات على الخصائص الحرارية للخرسانة. وشملت هذه الخصائص الموصلية الحرارية والحرارة النوعية والانتشار الحراري. بالإضافة إلى ذلك، تم التحقيق في تقدم معالجة الخرسانة الطازجة عن طريق قياس تغير قوة الضغط مع الوقت حتى 28 يومًا. ثم تم التحقق من آثار هذه التغيرات على الخصائص الفيزيائية والميكانيكية الأخرى. وتشمل هذه الخصائص الهبوط للخرسانة الطازجة وقوة الانضغاط والكثافة وامتصاص الماء للخرسانة المعالجة بالكامل. اشتملت المتغيرات المستقلة لهذه الدراسة التجريبية على نوع المادة المضافة ونسبة الإضافة ووقت المعالجة. بالإضافة إلى ذلك، تم تطوير نموذج لاستهلاك الطاقة في المباني للتحقيق في مستوى التوفير الاقتصادي الممكن باستخدام الخرسانة المحسنة.

تشير النتائج إلى أن زيادة نسبة إضافة جزيئات السيراميك أو أكسيد الكروم يقلل من الموصلية الحرارية للخرسانة. هذا يرتبط بانخفاض محدود في قوة الضغط. وبالمثل، فإن زيادة النسبة المئوية للكولين في الخليط يقلل من التوصيل الحراري حتى 10 ٪ نسبة إضافة. ومع ذلك، مع زيادة النسبة المئوية للإضافة (15 و20٪) من الكولين تزيد الموصلية الحرارية. من ناحية أخرى، تؤدي زيادة النسبة المئوية لإضافة أكسيد الألومنيوم إلى زيادة الموصلية الحرارية للخرسانة. يتم أيضاً عرض آثار هذه الإضافات على قابلية التشغيل وامتصاص الماء وقوة الضغط للخرسانة المحسنة. تشير حسابات النموذج المصمم إلى أنه يمكن تحقيق توفير حوالي 8 ٪ من الطاقة المستخدمة للتدفئة والتبريد عند استخدام جزيئات نفايات السيراميك بنسبة إضافة 20 ٪ كبديل للأسمنت في خرسانة الجدران لمبنى سكني محدد.

الكلمات المفتاحية: الخرسانة، العزل الحراري، الموصلية، الكولين، أكسيد الألومنيوم، أكسيد الكروم، جزيئات السيراميك.

DECLARATION

I declare that the Master Thesis entitled "Improving energy saving in buildings by enhancing concrete thermal insulation characteristics using mineral additives" is my own original work and herby certify that unless stated. All work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

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DEDICATION

"Say: Allah will see your works and so will His Messenger and the believers; then you shall be returned to the Knower of the unseen and the visible and He will inform you of what you were doing." Quran, At-Tawba [9.105]

Praise be to Allah in the beginning and in the end

To my true source of hope, to the people who keep me going through struggles and hardships, my dear husband and my dear parents.

To my dear brothers and sisters, your big hearts and pure souls only match your encouragement and continuous support.

Thank you from depths of my heart.

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Above all, to the great almighty, the creator of knowledge and wisdom, for his countless blessings.

From the heart, thank you.

Table of Contents

List of Abbreviations

k	Thermal Conductivity
Q	Electric Power or Rate of Heat Transfer
t	Time
L	Thickness of Concrete Specimen
A	Area of Concrete Specimen
ΔT	Temperature Difference
ASTM	American Society for Testing Materials
PS	Palestinian Standard
w/c	Water/Cement
$\boldsymbol{\rho}$	Density
$\boldsymbol{\alpha}$	Thermal Diffusivity of Cured Concrete
CWP	Ceramic Waste Particles
WA	Percentage Water Absorption
$\boldsymbol{c_p}$	Specific Heat of Cured Concrete
T	Temperature
$\boldsymbol{m_w}$	Mass of Water
$\boldsymbol{m_c}$	Mass of Concrete Specimen

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Chapter One
Introduction

CHAPTER 1

Introduction

1.1 General Aspects and Motivations

The continuous increase in the population and limited natural energy sources make the energy conservation around the world a very important issue. Thus, energy-saving measures are increasingly being implemented in all sectors. The construction sector is responsible for an important portion of the world's energy consumption. In most world's countries, one third of the overall energy consumption and thirty percent of greenhouse gases emissions are referred to the buildings [1,2]. Because of most persons spend around ninety percent of their lives in the buildings [3], thermal comfort and energy conservation in the buildings are interesting topics. The energy required for cooling, heating and comfort of buildings depends heavily on the physical and thermal properties of building materials [4].

One of the most important building materials worldwide is concrete. More than 10 billion tons of concrete are produced worldwide every year [5]. The demand on concrete is expected to increase to around 18 tons per year by 2050 [6].

The researchers in recent years focused on improving the various properties of concrete to improve the quality of buildings in general. In previous work, most of the researchers attention were paid to the mechanical properties of the concrete. However, in the recent time, more studies are studying the thermal properties of the concrete as well as the mechanical properties because of the great importance of saving energy in the buildings.

The main thermo-physical properties of concrete include thermal conductivity, specific heat and thermal diffusivity. Thermal conductivity is the main thermal property that affects energy saving in buildings [7]. Thermal conductivity (k-value) is a material’s property that demonstrates its heat conduction capability [8]. The energy consumption of buildings is largely dependent on the thermal conductivity of the building materials [9].

Materials with low and moderate thermal conductivity can reduce the energy consumption and heat transfer in buildings, these include move after mineral wool, cork, wood and ceramic tiles [10,11]. Generally, materials with low k-values are suitable energy saving options in the building construction sector. Industries in the recent years are moving towards developing more environmentally sustainable methods and ways of the concrete industry.

With the expectation that the emissions of carbon dioxide by the cement industry will reach about 3.5 billion tons in the world per year by 2025 [12], it is very crucial to find alternative materials of the cement. The production of the cement for use in the concrete industry are creating great amounts of the greenhouse gasses and it has a negative impact on the environment.

In recent years, researchers had focused on improving concrete properties by adding different additives to the concrete mixture. These include plant residues that reduces thermal conductivity of concrete and increases heat insulation. However, they reduce the compressive strength [13-15]. In previous studies, other additives added to the concrete included silica fume, wood shavings, crushed recycled glass, recycled high impact polystyrene (HIPS) and silica aerogel particle. All of these reduce the thermal conductivity of the concrete [16-20]. However, more studies are needed to find other types of improved concrete with good thermal insulation to reduce energy consumption in buildings around the world.

Supplementary cementing materials derived from industrial waste materials are becoming more prevalent as an alternative to cement in the industry. Kaolin and ceramic is an important raw material in various industrial sectors. The ceramic industry also produces large quantities of waste. Here also comes the importance of reusing these wastes for reducing their environment impacts.

In this research, various concrete additives are investigated. These include the chromium oxide, the aluminum oxide, the kaolin and the ceramic particles. Kaolin and ceramics are chosen because they may have pozzolanic activity and have low thermal conductivities. As for aluminum oxide and chromium oxide, they are chosen because they are never studied before and because the aluminum oxide is expansive and due to the contribution of the aluminum oxide in kaolin and clay. For chromium oxide, it is also chosen because that it is a potential industrial waste. In order to bridge the knowledge gab in this field, the effect of the aforementioned additives on the different properties of concrete are studied in this thesis. These include the thermal conductivity, the specific heat, the compressive strength, the water absorption, the workability and the density of the concrete. These additives are used as partial substitutes of cement weight in the concrete mixture with several replacement ratios. As the aluminum oxide was not previously studied as an additive in concrete. Previous researchers only studied the effect of the chromium oxide addition in the concrete mix on the durability of concrete. Kaolin and ceramic particles have not been studied before in terms of the effect on specific heat and thermal diffusivity of concrete.

1.2 Background

The research field of energy saving in buildings usually requires backgrounds in both heat transfer and concrete technology fields. It also deals with energy conservation in buildings.

From heat transfer prospective, thermal conduction is the transfer of heat by microscopic collisions of atoms and molecules and by the movement of electrons within a body.

To determine the ease with which a given medium conducts, engineers use thermal conductivity (k), which also known as conductivity coefficient or conductivity constant. The thermal conductivity (k): is defined as the quantity of heat transfer (Q) transmitted in the time (t) through a thickness (L) in a direction normal to a surface of the area (A) and because of a temperature change (ΔT).

Steady state conduction is the shape of the conduction which happens when the difference of temperature driving the conduction is constant, so that, the spatial distribution of the temperatures in the conducting object does not change any further with time. In steady state conduction, similar laws to this direct current electrical conduction can be applied to "heat currents". In such cases, thermal resistances may be taken as analogs of electrical resistors. In such cases, the temperature plays the role of the voltage, and the heat transferred per unit time is the analog of electric current.

In transient conduction, the temperatures changes with time (non steady-state conduction).

The law of heat conduction, also known as the Fourier law, states that the time rate of heat transfer through a substance is proportional to the negative temperature gradient and to the area, perpendicular to that gradient, through which the heat flows. The heat flux is the amount of energy that flows through a unit area per unit time.

Thermal conductivity is often treated as constant, although this is not always true. While generally the thermal conductivity of a material varies with temperature. The variation can be small over a wide range of temperatures for some common materials.

In the field of concrete technology, thermal conductivity is the most important thermal property that controls energy loss in buildings. Concrete has a moderate thermal conductivity, which much lower than that of metals, but significantly higher than that of other building materials such as wood. Thus, concrete is a poor insulator.

1.3 Problem Statement

Ideally, the floors, ceilings and walls of buildings should be perfectly insulated. There should be no loss of energy in buildings. However, in reality, the floors, ceilings and walls of the buildings are relatively conductive material for heat conduction. There are major energy losses in the buildings.

As consequences, the increase in the amount of energy wasted in buildings, increases the heating and air conditioning costs. This increases the cost of achieving thermal comfort in buildings and the fixed operating cost of building energy systems.

The proposed solution for this problem is by adding additives to the concrete mix so that they reduce the thermal conductivity of the concrete and increase its thermal insulation efficiency.

1.4 Research Questions and Hypothesis

Based on the identified problem in the previous section, the following research questions need to be addressed:

Main research question:

What is the effect of modifying concrete with selected mineral additives on its thermal insulation characteristics and energy saving in buildings?

The main problem is to perform a parametric experimental study investigating the proposed product of enhanced concrete using selected mineral additives. These include chromium oxide, aluminum oxide, kaolin and ceramic waste particles.

Sub-questions:

1. What are the effects of using the selected mineral additives on the thermal characteristics of concrete including thermal conductivity and specific heat?
2. What are the effects of using the selected mineral additives on the compressive strength and its development process with time, water absorption and workability?
3. What is the level of economic saving that can be obtained from the application of the enhanced concrete for a selected residential building?

Hypothesis:

It is hypothesized that adding the proposed additives to the concrete mixture will reduce the thermal conductivity of the concrete and hence will increase its thermal insulation.

Thus, it will reduce energy consumption in buildings and will reduce the energy costs for heating and cooling.

This is expected to yield a concrete with better mechanical properties or without a major negative impact on them.

1.5 Research Goal and Objectives

The goal of this research is to develop a new type of improved concrete product that can increase the insulation efficiency of buildings and reduce energy costs.

The study has the following objectives:

1. To provide a comprehensive literature review on additives improving concrete characteristics focusing on thermal insulation characteristics.
2. To develop a method for improving thermal insulation of concrete through mineral additives.
3. To confirm the technical feasibility of using the proposed additives in the concrete mix for improving thermal insulation efficiency without negative impacts on its mechanical characteristics.
4. To perform a parametric experimental study for utilizing the chromium oxide, aluminum oxide, kaolin and ceramic particles for improving concrete thermal characteristics.

1.6 Research Significance and Relevance

This research is very important for construction industry and energy sector. The importance of this research stems from the great benefits from the success of new products in the field of energy conservation, environment and saving in the cost of operating buildings.

The great importance of this research lies in the success of the new products of improved concrete in increasing the thermal insulation in buildings, and without significantly affecting the other properties of concrete. Increased thermal insulation means greater comfort in buildings, saving on heating and cooling costs, and saving on the amount of energy needed.

Another sustainability advantage of this work may be achieved through the enhanced concrete durability by having improved concrete resistance against freezing and thawing cycles. Thus, the service life of the enhanced concrete will increase and the likelihood of concrete collapse with time will decrease.

The relevance of this field to renewable energy is indicated by the interest of various international scientific journals that are interested in publishing articles in the subject of improving thermal properties of concrete. Some of their titles reflect the key words of renewable energy and green buildings. These include Renewable and Sustainable Energy Reviews, Energy and Buildings, Journal of Advanced Concrete Technology, and Journal of Building Engineering, which all are published by Elsevier. This highlights that these subjects draw the attention and interest of researchers in renewable energy as well as civil engineering.

1.7 Research Approach

The main research methodology for this study is experimental. The data obtained and the information are collected from the results of the performed experiments. In addition, the methods include literature reviewed.

A simple simulation system is implemented for estimating and comparing energy losses in a selected residential building with and without the modified concrete.

Methods are adopted to determine the thermal conductivity, the specific heat, the compressive strength, and other mechanical properties of the enhanced concrete.

Experiments run to confirm the technical feasibility of the proposed product. This is followed by a parametric study for investigating the effects of experimental parameters on the enhanced concrete characteristics.

Research variables are defined as follows:

The dependent experimental variables include the thermal conductivity, the specific heat, the thermal diffusivity, the compressive strength, the water absorption, and the workability.

The independent experimental variables include the additive type, the percentage addition, and the curing time.

1.8 Scope and Thesis Outline

This thesis consists of seven Chapters.

Chapter 1 – Introduction

This chapter contains a brief introduction to the work. A general background, purpose and research questions of this thesis are defined and the general methodology is introduced.

Chapter 2 – Literature review

This chapter presents a literature review, containing all topics that have been studied in the areas of this research and where the previous researchers arrived in their research. The knowledge gab in the previous research and what can be added in this area are also be highlighted.

Chapter 3 – Experimental work

This chapter describes the experimental work that represents a large part of the work of this thesis. The test set-up, concrete casting and materials are presented here. Tests were performed in many parts; this chapter contains a description of the method for the experimental work.

Chapter 4 – Results and Discussion

This chapter describes the results for the experimental work; a discussion on the results is made together with reflections on what it may depend on and what they reflect on. Comparisons of the results with previous finding are presented.

Chapter 5 – Conclusions and Recommendations

This chapter gives a summary of thesis and lists the main findings of this research; the general conclusions are stated. Conclusions are made on the experimental work, calculations, results, comparisons, and analysis. Potential further research issues are also included in this chapter.

Chapter Tow

Literature Review

CHAPTER 2

Literature Review

2.1 Introduction

The purpose of this literature review is to find, read, and analyze the body of the literature which been published in books, research papers, journals, conferences and thesis containing all topics that have been studied in the areas of this research and where the previous researchers arrived in their research. Previous reviews on energy saving in buildings, concrete and its thermal properties are studied in order to analyze more valuable information associated to the buildings energy saving. In this chapter, the review on issues related to the properties of the concrete through the addition of the chrome oxide, aluminum oxide, kaolin and ceramic particles into concrete mix also analyzed. The knowledge gab in the previous research and what can be added in this area are also be highlighted.

2.2 Energy Saving in Buildings

Thirty percent of the world's total energy consumption is attributed to buildings in most countries [1]. With an increasing global interest in environmental and energy issues, the construction sector holds a great potential for saving the energy.

In the recent years, significant pains have been made to reduce the energy consumption and improve the energy efficiency. The idea of energy efficiency in the buildings is connected to the energy supply, which needed to achieve eligible environmental conditions, which can minimize energy consumption in the buildings [21].

There are many different methods to reduce the energy use in buildings, ranging from simple behavioral adjustments to extensive home improvements. These include: weatherizing home and insulating home walls [22]. Insulation plays a key role in lowering the utility bills. Insulation is a way to save money and make the home more comfortable.

Among the best methods of isolation are insulating spray foam, solid foam insulation, cellulose insulation, Fiberglass Batts and radiant Barrier [23]. Another method of insulation is by increasing the thermal insulation of building materials. One of the most important building materials is concrete.

2.3 Introduction to Concrete

The word concrete comes from the Latin word “concretus”, which means hardened or solid. Concrete was a name applied to any composition consisting of crushed stone, sand, gravel or other coarse material, and bound together with the cementations materials, such as cements and lime. When water is adding to the mix, it undergoes a chemical reaction and hardens. Concrete has been used in the construction sector for over 2000 years [24].

Concrete is a component, which is the second most consumed material in the world, while water is the most used substance in larger amounts [25]. Obviously, each person in the world utilizes around one ton of concrete annually. When ecological and continual aspects are considered, concrete industry is seen these days as the largest consumer of natural resources and important source of waste.

2.4 Hydration of Cement

The composition of a typical Portland cement type I 1 is listed by weight percentage in table 2.1 [26].

Table 2.1: Composition of Portland cement type I with chemical composition and weight percent [26].

Cement Compound	Weight Percentage	Chemical Formula
Tricalcium silicate	53%	Ca_3SiO_5 or $3CaO{\cdot}SiO_2$
Dicalcium silicate	24%	Ca_2SiO_4 or $2CaO{\cdot}SiO_2$
Tricalcium aluminate	8%	$Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$
Tetra calcium aluminoferrite	8%	$Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$
Gypsum	7%	$CaSO_4{\cdot}2H_2O$

When the water is added to the cement, each of the compounds of the cement undergoes to a hydration reaction and contributes to the final product of the concrete. Only the calcium silicates contribute to the strength. Tricalcium silicate is responsible of most of the early strength at the first seven days. Dicalcium silicate that reacts more slowly, contributes only to the strength at the later times [27]. The equation for the tricalcium silicate hydration is given by:

Tricalcium silicate + Water → Calcium silicate hydrate + Calcium hydroxide + heat

$$2\,Ca_3SiO_5 + 6\,H_2O \rightarrow Ca_3Si_2O_7{\cdot}3H_2O + 3\,Ca(OH)_2 \tag{2.1}$$

Dicalcium silicate by its hydration affects the strength of the concrete. Dicalcium silicate interacts with water in a manner similar to tricalcium silicate, but more slowly [27]. The products of the hydration of dicalcium silicate are same as those for tricalcium silicate:

Dicalcium silicate + Water → Calcium silicate hydrate + Calcium hydroxide +heat

$$2\ Ca_2SiO_4 + 4\ H_2O \rightarrow Ca_3Si_2O_7 \cdot 3H_2O + Ca(OH)_2 \qquad (2.2)$$

The other main components of Portland cement also react with water. The hydration chemistry of them is more complex because it involves reactions with gypsum.

Hydration rate of the compound may be affected by a change in the concentration of another. Generally, the rates of hydration at the first few days graded from fastest to slowest:

Tricalcium aluminate> ticalcium silicate> tetracalcium aluminoferrite> dicalcium silicate.

The heat develops with the hydration of the cement due to the making and breaking of the chemical bonds during the hydration.

2.4.1 Pozzolanic Activity

A pozzolan is defined as (ASTM C125) ‘‘a siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties” [28].

The pozzolanic activity is a measure of the degree of reaction over time or the reaction rate between a pozzolan and Ca^{2+} or calcium hydroxide ($Ca(OH)_2$) in the presence of water. The rate of the pozzolanic reaction is dependent on the intrinsic characteristics of the pozzolan, such as the chemical composition, the active phase content and the specific surface area [28].

The pozzolanic reaction is the chemical reaction that occurs in the portland cement with the addition of pozzolans [28].

Chemically, the pozzolan reaction occurs between calcium hydroxide, also known as portlandite ($Ca(OH)_2$), and silicic acid (written as H_4SiO_4 or $Si(OH)_4$):

$$Ca(OH)_2 + H_4SiO_4 \rightarrow CaH_2SiO_4 \cdot 2\ H_2O \qquad (2.3)$$

It is summarized in abbreviated notation of cement chemists:

$$CH + SH \rightarrow C\text{-}S\text{-}H \qquad (2.4)$$

Sufficient amount of free calcium ion and a high pH of 12 and more are needed to initiate and maintain the pozzolanic reaction [28]. This is because at a pH of around 12, the solubility of aluminum and silicon ions is high enough to support the pozzolanic reaction.

2.5 Concrete Standard Mix Design

Table 2.2 gives some standard mix designs specification for concrete classes. These mixtures are designed as follows and refers the concrete type to a kilogram cement in one cubic meter of concrete. Table 2.3 contains the mix design details of different types of concrete samples.

Table 2.2: Selected standard mix designs specification for concrete classes [29].

Concrete Type	Compressive Strength (MPa)	Slump (mm)	Water Absorption (%)
B200	18 - 22	25 - 75	2 – 5
B250	22.5 - 27.5	25 - 100	2 – 5
B300	27 – 33	25 - 75	2 – 5

Table 2.3: Mix design details of different types of concrete samples [30].

Type	w/c ratio	Water (kg)	Coarse sand (kg)	Fine sand (kg)	Cement (kg)	Gravel (kg)
B300	0.6	180	797	212	300	900
B350	0.43	150	818	214	350	880
B400	0.5	200	734	200	400	780

2.6 Properties of Concrete

There are many mechanical and thermal properties of concrete. The basic mechanical properties of concrete include compressive and tensile strength, stress-strain response and modulus of elasticity of constituent materials. The basic thermal properties of concrete include thermal conductivity, specific heat and thermal diffusivity. In this research, the properties studied are the workability, the compressive strength, the water absorption, the density, the specific heat, the thermal diffusivity and the thermal conductivity.

Concrete standards are of great importance when it comes to assessing and testing concrete. The cement and concrete standards enable laboratories around the world to assess and examine concrete mixtures to guarantee their strength and safety. These standards contribute in identifying the distinct specifications of concrete such as strength, elasticity, hardness and workability. Concrete standards are useful for the evaluation and testing of concrete.

2.6.1 Workability (Slump Test)

Workability is a property of the fresh mixed concrete that determines the ease with which it can be mixed, laid, consolidated and finished properly without separation. It can also be used as an index of an improperly mixed batch [31].

The workability of the fresh concrete is measured by the slump test. The test is very popular because of the simplicity of apparatus used and simple procedure. The slump test is made according to ASTM C143.

Slumped concrete takes various forms, and according to the shape of the slumped concrete, slumped is called a true slump, shear slump or collapse slump as in figure 2.1.

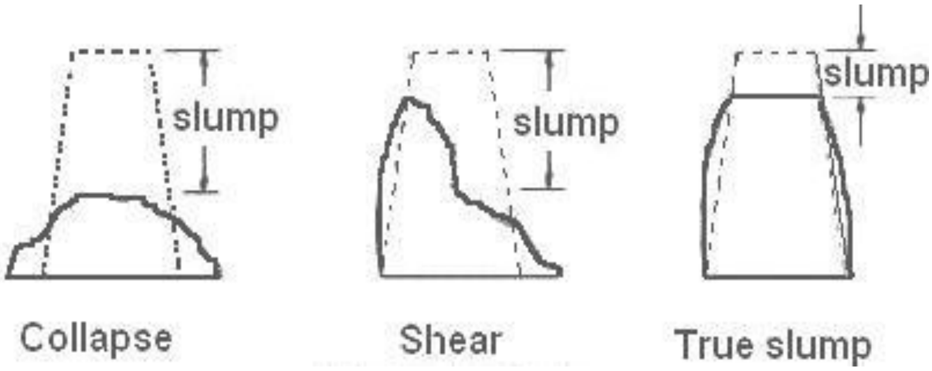


Figure 2.1: Types of concrete slump.

If the slump is shear or collapse, a fresh sample of concrete should be taken and the test repeated. Only the true slump is of any use in test. Generally, the collapse slump will mean that the mixture is too wet or a high workability mixture, in which the stagnation test, is not appropriate.

2.6.2 Compressive Strength

The compressive strength of hardened concrete is the most important property of it. Since the compressive strength continues to increase with the continuing hydration of cement, it is a function of age that is the time after the casting.

Compressive strength of concrete is the value of uniaxial compressive stresses reached when the concrete fails completely [30]. Compressive strength also is the ability of the material or structure to carry the loads on it without any deflection or crack.

The compressive strength is tested on either the cube or the cylinder. ASTM C109/C109M provides standard test method for compressive strength of cube concrete specimens. For cube test of concrete two types of specimens, either cubes of (15 x 15 x 15) cm or (10 x 10 x 10) cm depending on the size of the aggregate. For most of the concrete works cubical molds of size, (10 x 10 x 10) cm are commonly used. Compressive strength of concrete cube test provides an idea about most of the characteristics of concrete. By this single test, one judges that whether concreting has been done properly or not.

The compressive strength of the concrete for general construction varies from 15 MPa to 30 MPa and higher for commercial and industrial structures. Most commercially produced concrete has compressive strengths between 20 and 40 MPa. Strength of concrete depends on water-cement ratio, strength of cement use, quality of concrete materials and quality control during production of concrete [30]. The compressive strength formula for any substance is the load applied at the point of failure to the cross-sectional area of the face on which the load was applied.

Concrete gains the compressive strength over time after casting. It takes a large time for the concrete to gain 100% strength and still the same time is unknown. The table 2.4 shows the compressive strength gained by concrete after one day, 3, 7, 14, 21 and 28 days with respect to the grade of concrete.

Table 2.4: Compressive strength gained by concrete with curing age [32].

Age	Strength per cent
1 day	16%
3 days	40%
7 days	65%
14 days	90%
21 days	94%
28 days	99%

The rate of gain of concrete compressive strength is higher during the first 28 days of casting and then it slows down [32]. Thus, it is evident that the concrete is rapidly gaining its strength in the initial days after casting, i.e. 90% in only 14 days. When its strength reached 99% in 28 days, still concrete continues to gain strength after that period, but that rate of increase in compressive strength is much lower compared to that in 28 days.

After 14 days of casting concrete, concrete gains only 9% in next 14 days period. Therefore, the rate of gain of strength decreases. There is no clear idea up to when the concrete gains the full strength, 1 year or 2 year, but it is assumed that concrete may gain its final strength after 1 year. Thus, since the concrete compressive strength is 99% in 28 days, it is almost close to its final strength, therefore it rely on the results of compressive strength test after 28 days and use this strength as the basis for the design and evaluation.

2.6.3 Thermal Conductivity

Thermal conductivity is the most important thermal property concrete. Low heat conductivity concrete reduces the energy consumption in buildings. Thermal conductivity (k-value) is a property of material that demonstrates its ability to conduct heat.

2.6.3.1 Measurement Methods of Concrete Thermal Conductivity

Several steady and transient methods can be used to measure the thermal conductivity of concrete. The steady state is a constant heat transfer, as the temperature or heat flow does not depend on time. This method is commonly chosen for testing homogeneous materials. This method takes longer time, but the achieved k-value is more accurate.

The transient method depends on time and the temperature changes over time. An advantage of the transient method is the ability to look at moisture content, but a disadvantage is the need to repeat the test multiple times to obtain accurate results [33]. This method is usually used for heterogeneous materials. In summary, the researchers is using four methods to measure the k-value of the cement based materials.

1. Steady State Boxes Method

Boxes method is a method for determining the thermal conductivity of the concrete based on the energy evaluation of system. The device contains one hot room and one cold room. The sample is placed between the hot and cold sides [34-36].

2. Steady State Hot Plate Method

Protected hot plate is a useful method for evaluating the thermal conductivity of insulation materials [18, 37-43].

3. Transient Hot Wire Method

The hot wire method is a transient method that relies on measuring the improved temperature at a specific distance from the hot wire, which is a linear heat source inside the test material [16, 44-53].

4. Transient Plane Source Method

Using transient plane source method, the thermal conductivity is measured based on the power input and time-dependent variation of both the transit plane and the transit line sources [17, 54-55].

In conclusion, the application of specific devices and methods may depend on the availability of specific equipment in the research laboratory. Besides, different sample sizes and shapes are used depending on the test requirements for a specific device. Table 2.5 lists the specimen sizes that ranged between (50×50×50 and 300×300×55) mm^3, testing ages, which was often 7 or 28 days and measurement techniques used in previous studies. Figure 2.2 shows the percentages of the different k value measurement methods used in 25 studies.

Cost and availability of equipment, the ability to measure for moist samples and time of experimental measurements may be some reasons for using transient methods instead of steady-state methods. Different ways may lead to different thermal conductivity values. There is insufficient information in the literature about suitable ways for measuring the thermal conductivity of the concrete. It is important to determine an appropriate method to measure the thermal conductivity of concrete to achieve accurate values for calculating energy consumption in buildings.

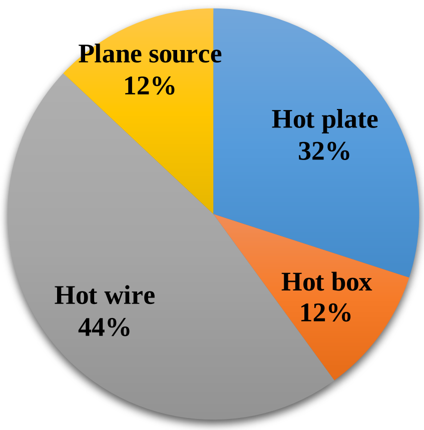


Figure 2.2: Percentages of thermal conductivity measurement methods employed in previous studies [56].

Table 2.5: Summary of thermal conductivity measurement techniques [56].

Measurement techniques	The research	Specimen size (mm^3)	Testing age
Steady state boxes method	Influence of the moisture content on the thermal conductivity value of the wood concrete composite [34]	270×270×20	NA
	The thermal conductivity value of the insulator by adding vegetable fibers [35]	270×270×60	28
	Effect of the humidity on the thermal conductivity value of lightweight concrete [36]	NA	28
Steady state hot plate method	The thermal conductivity value of self-compacting concrete by using Perlite lightweight aggregate [37]	Cylindrical 180mm×15mm	NA
	The thermal conductivity value of oil palm shell foamed lightweight concrete [38]	300×300×50	28
	The thermal conductivity value of oil palm shell foamed geopolymer lightweight concrete [39]	300×300×55	28
	The thermal conductivity value of novel form-stable fiber composite concrete [40]	NA	NA
	The thermal conductivity value of newspaper sandwiched aerated lightweight concrete [41]	300×300×50	NA
	The thermal conductivity value of concrete using crushed recycled glass as a fine aggregate [18]	300×300×30	28
	The thermal conductivity value of foamed lightweight and polystyrene foamed concretes [42]	200×200×40	NA
	The heat capacity and thermal conductivity value of inhomogeneous concrete with incorporated microencapsulated-phase change materials (PCM) [43]	150×150×80	About 150
Transient hot wire method	The thermal conductivity value of concrete using bottom ash as cement replacement [44]	50×50×50	7
	The thermal conductivity value of air permeable concrete as wall construction material [45]	100 mm in diameter and 100 mm high	7
	The thermal conductivity value of hemp concretes [46]	150×100×50	NA
	The thermal conductivity value of modified waste expanded polystyrene lightweight aggregate concretes [47]	40×110×160	NA
	The thermal conductivity value of expanded perlite lightweight aggregate concrete by mineral admixtures [48]	100 ×80 ×40	NA
	Effect of blast furnace slag (BFS), silica fume (SF), class C fly ash (FA), SF+FA, SF+BFS and FA+BFS on the k-value [16]	100×80×40	28
	The thermal conductivity value of diatomite and pumice lightweight aggregate concretes [49]	Cylindrical 50mm×100mm	28
	The k-value of low-strength lightweight concrete [50]	100×100×100	28
	The thermal conductivity value of four different types of rocks as aggregate in dry and saturated condition [51]	120×120×40	27
	Relation of the k-value and mineral admixtures [52]	110×160×40	28
	Influence of class C fly ash (FA), blast furnace slag (BFS) and a combination of FA and BFS on the k-value of concrete [53]	110×160×40	28
Transient plane source (TPS)	Changes in the thermal conductivity value of sand concretes by adding wood shavings [17]	100×100×50	NA
	Effect of moisture content on the thermal conductivity value of autoclaved aerated concrete [54]	100×100×30	NA
	The k-value of concrete with relative humidity of 10-30% [55]	150×150×150	28

NA: Not Available.

2.6.3.2. Factors Affecting the Thermal Conductivity of Concrete

Several factors influence the k-value of concrete. Considering these factors while casting and using concrete in buildings can lead to more sustainable and energy efficient buildings.

Kim et al. [57] considered seven factors effect on the thermal conductivity of mortar, cement paste and concrete. The seven factors are the water to cement ratio (w/c), mix type, temperature, age, humidity condition of the sample, fine aggregate fraction and total aggregate volume fraction. However, the most effective factors on the k-value of the cement paste and mortar are the w/c ratio and the mix type.

1. Moisture Content and Temperature

The thermal conductivity of concrete in the saturated state is greater than the dry state because of the thermal conductivity of water that is 25 times higher than it of air [58]. Moreover, the thermal conductivity of water used in mixtures is dependent on temperature.

The influence of moisture content and temperature on the thermal conductivity of materials is related to the basic properties of the material. These include the internal pore composition and density [59]. To reduce the influence of the moisture on the thermal conductivity of materials, experiments can be made in oven-dry conditions.

There are not enough data about the relationship between the moisture content and the thermal conductivity value of concrete. For most previous studies, the k-value of cement-based materials was measured in the case of saturated or oven-dry condition. However, in the real settings, the concrete does not remain in a saturated state and may not reach to the completely dry oven state. Generally, the thermal conductivity value of concrete increases with a higher value of the moisture content.

2. Type of Aggregate

Aggregate represents about 60 to 80% from the volume of concrete. The thermal conductivity value of concrete can be changed using different types of aggregates. The k-value of the concrete increased by keeping the sand ratio unchanged and raising the portion of the coarse aggregate volume fraction [8]. Moreover, the use of lightweight foam concrete instead of the traditional aggregate in concrete reduces the k-value due to the porosity of the lightweight aggregate.

There are solid wastes in the agricultural sector that can be used in concrete mix. Research shows that solid waste, which include coconut husk [13], rice husk and tobacco waste [15], can be successfully used as aggregates in the concrete mixes. These are porous in nature, so applying these wastes to the concrete reduces its density.

The addition of more wood shavings caused a reduced k-value of sand concrete and thus enhanced its thermal insulation ability [17].

3. Type of Cementitious Material

Bottom ash is a waste from coal combustion. Bottom ash can be used as a substitute for aggregates as well as replacing cement in concrete [44].

Wongkeo et al. [44] checked the thermal conductivity of sterilized concrete using bottom ash. Bottom ash was used as a substitute for Portland cement with 0%, 10%, 20% and 30% by the weight. They reported that the k-value was increased by adding bottom ash to the mix due to the increasing unit weight of the concrete.

Demirboğa and Gül [48] examined the effect of replacing 10, 20 and 30% Portland cement with fly ash and silica fumes (the most complementary cement material available worldwide) on the k-value of lightweight perlite concrete. It was reported that these cement materials could reduce the k-value of concrete at all levels of replacement.

Demirboğa also studied the k-value of mortar containing silica fume, blast furnace slag and fly ash as a substitute for cement in percentages of 10, 20 and 30%. The results of the test showed that the use of these cement materials reduced the k-value of the mortar.

Xu and Chung [60] examined the k-value of cement paste with 15% silica smoke and 0-2% silane as additives. They showed that adding silane alone in the mix improved thermal conductivity by 78%, while a mix of silica fume and silane increased the k-value by up to 38%.

4. Density of Concrete

The density (ρ) is defined as the mass per volume with SI units of kg/m^3. However, there is a statistically significant relationship between the value of thermal conductivity of concrete and the weight of the concrete.

Increasing the air voids in the concrete is a way for reducing the concrete density. The air voids are artificially created using aluminum powder or foam agent in foamed concrete that is classified in the cellular concrete group [61]. To reduce concrete density there is another way, which is to use lightweight aggregate instead of conventional aggregate.

Most of the previous studies indicated that the density of the concrete had the best relationship with k-value of concrete. Figure 2.3 shows the relationship between the thermal conductivity of concrete and the density of concrete. This relationship derived from 185 empirical data that available in the literature [56].

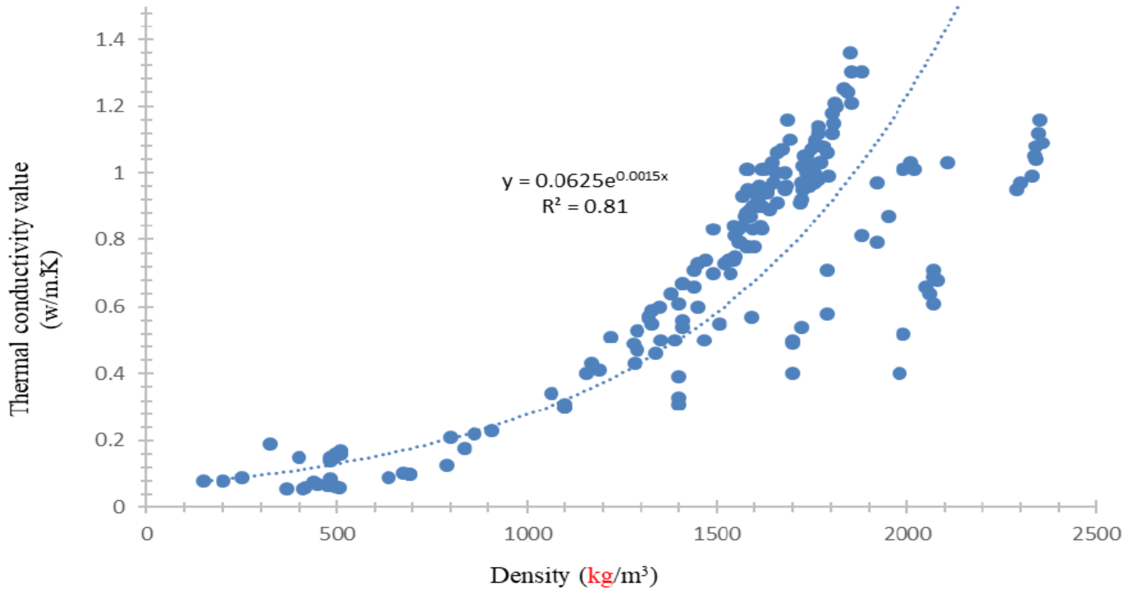


Figure 2.3: General correlation between thermal conductivity and density [56].

Therefore, Eqn. 2.1 can be used to predict the k-value of concrete with densities ranging from 150 to 2350 kg/m^3 [56].

$$k = 0.0625e^{0.0015\rho} \qquad (R^2 = 0.81) \qquad (2.5)$$

In this thesis, the focus is on the effect of the additives added to the concrete mix as a percentage of cement weight on thermal insulation efficiency of concrete.

2.6.4 Specific Heat (Heat Capacity)

Heat capacity is an important property of a substance that shows the ability of a substance to store heat energy. For that, it was important to study the heat capacity of the concrete. The specific heat of the concrete at the room temperature varies from 840 J/kg·K to 1800 J/kg·K with different aggregates types [62]. Usually, the heat capacity is expressed in terms of heat capacity that is the product of the concrete density and the specific heat. Specific heat of concrete is highly dependent on the moisture content and significantly increases with a higher water to cement (w/c) ratio.

2.6.5 Thermal Diffusivity

Thermal diffusivity is using to calculate the thermal conductivity. However, it represents the rate at which the temperature changes within a specific mass. It is represented by (α) and it is measured in meter square per hour [62]. Thermal diffusivity is like an index that facilitates the changes in temperature of concrete.

2.6.6 Density

The density of the concrete is defined as the mass per volume in kg/m^3 in the SI units. The unit weight of concrete (density) depends on the amount and the density of the aggregate, the amount of entrained air, the water to cement ratio and the additives. It is connected to many deterioration processes driven by the transport properties of concrete [63].

2.6.7 Water Absorption

The water is essential to the cement hydration, which gives the concrete its mechanical strength. The amount of water needed for this hydration must be correctly quantified. Too much water in the mix increases the porosity of the concrete, which reduces the mechanical performance and durability of the concrete. A lack of water in the mixture will lead to the incomplete cement hydration reactions and reduce the workability of the fresh concrete. Generally, concrete of low water absorption will afford better protection to reinforcement within it [30]. Water absorption is measuring according to ASTM C-642.

2.7 The Freeze and Thaw Cycles of Concrete

Freezing and thawing is a serious natural phenomenon that affects the properties of concrete. These phenomena occurred if the void spaces between particles of concrete are filled partially with water. During cooled weathers, when the temperatures drop below zero centigrade the void water will freeze and thus increase in volume. The increase in size will impose stresses on particles and will cause disintegration of concrete [64]. During summer, the frozen water between voids will start to melt and escape out of the concrete voids causing leaching of fine contents, which has been disintegrated due to stresses from ice lenses. The same process will repeat itself with larger ice lenses, bigger void spaces and more stresses on the solid particle at the next cooled season. The cyclic freezing and thawing between summer and winter seasons will cause continuous disintegration of concrete particles and eventually complete failure of the structural system.

2.8 Previous Studies of Concrete Additives

In recent years, researchers had focused on improving concrete properties by adding different additives to the concrete mix. In previous studies, other additives added to the concrete included silica fume, mineral wool, wood shavings, crushed recycled glass, recycled high impact polystyrene (HIPS) and silica aerogel particle. This all reduced the thermal conductivity of the concrete [16-20]. However, more studies are needed to find other types of improved concrete with good thermal insulation to reduce energy consumption in buildings around the world. The research methodology in this field is based on casting modified concrete and then measuring its mechanical and thermal characteristics. Table 2.6 is a summary of previous studies investigating the effects of using some materials in production of concrete.

2.8.1 Aggregate Replacement

Aggregates occupy about two-thirds of the volume of concrete. Thus, it has a great influence on the different properties of concrete. Therefore, many researchers have focused in recent years on finding some materials that are suitable substitutes for aggregates in the concrete mix in order to improve the different properties of concrete. Many materials are fully or partially used as replacement of coarse aggregate or fine aggregate. Table 2.7 is a summary of previous studies investigating some properties of enhanced concrete using some materials as an aggregate replacement.

Table 2.6: The effects of using some materials in production of concrete.

Admixture	Year	percent	Result	Advantages
Alum [65]	1995	10%	Compressive strength = 39.9MPa	Has excellent potential as a supplementary cementing material for high performance concrete production.
			Splitting tensile = 2.7MPa	
			Slump = 170 mm	
			Density = 2345 kg/m^3	
			Total scaling = 0.9 kg/m^3	
Silica fume [66]	2000		Compressive Strength of mortar = 87MPa	Prove the properties of high strength concrete more than when using this material separately.
			Compressive Strength of concrete = 68MPa	
Diatomite [67]	2007	5%	Compressive strength = 46.02MPa	Such as higher water demand, but higher compressive strength of Portland cement.
			Water absorption = 8.67 %	
			Flexural strength = 6.62MPa	
			Dry unit weight = 2208 kg/m^3	
Fly ash [68]	2010		Compressive Strength = 38MPa	Lower the cost of SCC
			Slump test = 645mm	
			Density = 2320 kg/m^3	
Dolomite Powder [65]	2010		Compressive Strength = 34MPa	Lower the cost of SCC
			Slump test = 550mm	
			Density = 2420 kg/m^3	
Fly ash and Dolomite powder [68]	2010	75%FA + 25%DP	Compressive Strength = 36MPa	Possibility to manufacture self-compacted concrete using dolomite powder and fly ash with acceptable hardened and fresh properties.
			Slump test = 635mm	
			Density = 2340 kg/m^3	
Clay [69]	2010	20%	Compressive strength = 30MPa	Minor strength loss possess increase durability performance.
			Water absorption = 14%	
Red mud [70]	2011	5%	Compressive strength = 30.2MPa	The percentages of waste materials in concrete mixtures do not affect the workability of concrete.
			Slump = 10.5 mm	
Diatomite [71]	2012	30%	Compressive strength = 9.18MPa	Noise insulation, **heat insulation**, thermal balance, fire resistance and esthetic purposes.
			Water absorption = 8.58 %	
			Density = 1880 kg/m^3	
			Heat Conductivity = 1.14kcal/m^{o}C	

Table 2.7: Some properties of enhanced concrete using some materials as an aggregate replacement.

Material	Year	Replacement %	W/C	Fresh density Kg/m3	Results
Steel slag [72]	2014	40%	0.55	2410	Slump in mm/CF = 13
					Compressive Strength = 28.3MPa
					Split Tensile Strength = 2.4726MPa
					Flexural strength = 6.8MPa
Copper slag [72]	2011	50%	0.35	2430	Slump in mm/CF = 130
					Compressive Strength = 47MPa
					Split Tensile Strength = 4.126MPa
					Flexural strength = 7.3MPa
Bottom Ash [72]	2014	10%	0.477	2281	Slump in mm/CF = 80
					Compressive Strength = 38.81MPa
					Split Tensile Strength = 3.2826MPa
					Flexural strength = 3.7MPa
Rubber [73]	1996	25%	0.5	2382.9	Compressive Strength = 19.6MPa
					Flexural strength = 3-5MPa
Glasses [74]	2009	20%	0.53	2382.9	Slump in mm/CF = 50
					Compressive Strength = 45.9MPa
					Flexural strength = 6.55MPa
crushed concrete [75]	2007	10%	0.56	2296	Slump in mm/CF = 52
					Compressive Strength = 31MPa

2.8.2 Cement Replacement

Among greenhouse gases, carbon dioxide contributes about 65% of global warming. The world's cement industry contributes about 7% of greenhouse gas emissions to Earth's atmosphere. Because of that, in order to address the environmental impacts associated with cement manufacturing worldwide, there is a global need to develop alternative links for making concrete. Consequently, extensive research is being done on the use of cement alternatives, using various materials. We talked about some of the materials that were used as alternatives to cement in the concrete mixture in section 2.6.3.2. However, when reviewing the different literature should have focused on the materials used in this thesis, which is as follows:

2.9 Review of the Used Additives in Previous Work

2.9.1 Ceramic Particles

Irassar et al. [76] examined the effect of adding ceramic waste particles (CWP) as cement replacement on the hydration products. It was reported that the addition of 8 to 40% CWP resulted in suitable pozzolanic activities after 28 days curing.

Vejmelková et al. [77] showed that incorporation of ceramic waste particles (CWP) at concrete as a cement replacement decreased the compressive strength by 10%, compared to the control specimen. On the other hand, Awoyera et al. [78] indicated that the addition of ceramic aggregates and powders, as replacements of sand, resulted in improving the compressive and the flexural strengths. Pokorny et al. [79] reported that the mortar specimens containing ceramic waste particles (CWP), as cement replacement, decreased the compressive and bending strengths, while enhancing the thermal insulation.

Pacheco et al. [69] showed that the concrete with 20% cement replacement although having a slight loss of strength possess increase durability performance. In addition, the results showed that the mixes of concrete with ceramic aggregate perform better than the control concrete mixes concerning the capillary water absorption and the compressive strength. Medina et al. [80] discover the durability of aggregate concrete, which made with aggregate containing 20 to 25% ceramic sanitary ware industry waste. The results showed that the concrete freeze-thaw resistance increased with the higher recycled aggregate content.

2.9.2 Chromium Oxide

Adnan Colak [81] foxed on the wear characteristics of concretes and limestone filler blended white Portland cement paste with and without chromium oxide. The results showed that the limestone filler blended white Portland cement paste wear losses were very high. Anyway, replacement of the limestone filler in the mixture by chromium oxide causes a significant decrease in the wear loss.

2.9.3 Kaolin

Research has shown that the residues and waste of the kaolin can be heated from these processes to produce a substance with pozzolanic properties [82]. Frias et al. [83] found similar results when paper sludge was calcined at an appropriate temperature, and indicate that it is suitable for use in the concrete industry. Roach and Angelica found that the collected residues from kaolin mining processes, which had a greater number of structural defects, required less temperature to achieve the pozzolanic properties, saving energy costs [82]. In addition, they found that these residues showed a higher reactivity than available commercially pozzolanic materials.

D. D. Vu. et al [84] dealed with the effects of partial substitution of Portland cement by calcined kaolin on durability characteristics, workability and compressive strength in concrete and mortar mixtures. Lotfy et al [85] concluded that use of kaolin waste decreased unit weight and worsened the workability irrespective of kaolin waste content. The incorporation of kaolin waste has a positive effect on the compressive strength, especially at 10% and 15% replacement levels after 28 days. KW substitution up to 15% showed porosity and water absorption values almost identical to the control concrete.

The metakaolin has a pozzolanic properties and is derived from clay kaolin by dehydration [86]. This clay is readily available throughout the world in large quantities making it a cost-effective alternative of cement [86]. Research has found that pozzolan offers several advantages to concrete such as lower temperature rise, improved durability performance and higher strength [87].

2.9.4 Aluminum Oxide

Muñoz et al [88] studied the effect of two combinations of silicon and aluminum oxides on the hydration reaction of cement and the porosity of the interfacial transition zone. The nanosilica–nanoboehmite mixes were found to accelerate the hydration reaction. When these materials were applied as thin nanoporous films on the aggregate, not only did all sol mixtures helped to decrease the total porosity but also contributed to the refinement of the porosity in the cement paste adjacent for the aggregate.

Alabadan et al [89] examined Ordinary Portland Cement and Bambara Groundnut Shell Ash concrete. The ash contained 1.75% aluminum oxide. The ash was used in the mix to replace cement. The strength of concrete/ash increased with the curing period but decreased with increasing ash percentage.

2.10 Gab of Knowledge in Previous Work

Previous researchers investigated various thermal properties of concrete, including thermal conductivity. The research methodology in this field is based on casting modified concrete and then measuring its mechanical and thermal characteristics. The factors affecting the thermal conductivity of concrete were investigated. More research is required evaluate the effect of using different types of additives to the concrete mixture on the thermal conductivity of concrete. Various mineral oxides have not been investigated as potential additives to concrete for improving its thermal insulation efficiency. Most of previous work focused on mechanical characteristics and water absorption.

Most recent studies focused on the effect of additives on concrete thermal conductivity. Less attention was paid to specific heat measurement. Less attention was given to combining the thermal and mechanical properties. In this thesis, the focus is on the effect of additives, which were not given sufficient efforts in previous studies.

Previous researchers only studied the effect of chromium oxide addition in the concrete mix on the durability of concrete. The addition of aluminum oxide was not previously studied as an additive to concrete mix. There have been various research studies on the effect of adding ceramic particles and kaolin on concrete mechanical properties and on the thermal insulation of concrete. However, there was a shortcoming in previous studies on the effect of adding ceramic particles and kaolin in the concrete mix on concrete heat capacity and thermal diffusivity.

Table 2.8 presents a summary of the findings of previous studies on the effect of using kaolin, aluminum oxide, chromium oxide and ceramic particles in the concrete mixture.

Table 2.8: A summary of the findings of previous studies on the effect of using kaolin, aluminum oxide, chromium oxide and ceramic particles in the concrete mixture.

Additive	Thermal conductivity	Heat capacity	Thermal diffusivity	Compressive strength	Water absorption	Slump
Kaolin	↓	NA	NA	↓	NA	↓
Aluminum oxide	NA	NA	NA	NA	NA	NA
Chromium oxide	NA	NA	NA	NA	NA	NA
Ceramic particles	↓	NA	NA	↓	NA	↓

NA: Not Available. ↑: Increased. ↓: Decreased.

Chapter Three

Experimental Work

CHAPTER 3

Experimental Work

3.1 Introduction

This chapter demonstrates the experimental work, which is the main part of this thesis. The details of materials, equipment and procedures are presented. In addition, the work steps are explained in details. In addition, the equations that were used in the calculations are explained.

3.2 Materials

The following represents the materials that were used to study the effects of utilizing chromium oxide, aluminum oxide, kaolin and ceramic particles into concrete mix.

1. **Portland Cement:** The cement used in this study was Portland cement type I satisfying the requirements of the standard ASTM C114- 11b.
2. **Fine Aggregate:** Natural silica sand conforming to ASTM C778-13 was used throughout this study. It was conformed to possess an especially high level of cleanliness, which is applicable for concrete mix.
3. **Natural Coarse Aggregate (Sedimentary Rock Source):** Two sizes (medium and fine) of angular aggregates of crushed limestone were used. They conformed to the requirements of the standard ASTM as in sec 3.4.1.
4. **Water:** Potable water was used as mixing water.
5. **Concrete Additives:** Kaolin, aluminum oxide, chromium oxide and ceramic particles. These particles are shown in the following figure 3.1. The characteristics of these materials are listed in tables 3.1, 3.2, 3.3 and 3.4.

Kaolin	Aluminum Oxide	Chromium Oxide	Ceramic Particles

Figure 3.1: Images of the used additives.

Table 3.1: Chemical composition of ceramic particles.

Content	%	Content	%
SiO_2	63.45	CaO	8.18
Al_2O_3	13.98	Na_2O	0.90
Fe_2O_3	5.39	K_2O	2.43
TiO_2	0.77	SO_3	0.10

Table 3.2: Chemical composition of kaolin.

Content	%	Content	%
SiO_2	57.63	CaO	0.35
Al_2O_3	37.77	MgO	0.60
Fe_2O_3	0.86	K_2O	1.80
TiO_2	0.61	P_2O_5	0.31

Table 3.3: Properties of aluminum oxide.

Chemical formula	Al_2O_3
Molar mass	101.960 g/mol
Appearance	White
Density	3.99 g/cm^3
Melting point	2072 °C (3762 °F; 2345 K)
Boiling point	2977 °C (5391 °F; 3250 K)
Solubility in water	Insoluble
Solubility	insoluble in diethyl ether practically insoluble in ethanol
Magnetic susceptibility (χ)	-37.0×10^{-6} cm^3/mol
Thermal conductivity	30 W/(m.K)

Table 3.4: Properties of chromium oxide.

Chemical formula	Cr_2O_3
Molar mass	151.9904 g/mol
Appearance	light to dark green
Density	5.22 g/cm^3
Melting point	2435 °C (4415 °F; 2708 K)
Boiling point	4000 °C (7230 °F; 4270 K)
Solubility in water	Insoluble
Solubility in alcohol	insoluble in alcohol, acetone, acids
Magnetic susceptibility (χ)	$+1960.0\times10^{-6}$ cm^3/mol
Thermal conductivity	0.45 W/(m.K)

The source of fine aggregate and medium aggregate was Abu Shusheh Crusher Corporation. The source of natural sand was Naqap desert. Chromium oxide, aluminum oxide and kaolin were obtained from a local supplier (ICL Corporate). Ceramic waste particles were obtained by crushing a ceramic waste obtained from a local ceramic factory.

3.3 Equipment

The following apparatus and equipment were used in this project to study the effect of utilizing chromium oxide, aluminum oxide, kaolin and ceramic particles into concrete mix:

1. Sieves to analysis the particle size distribution of the aggregate.
2. Scales, trowel, concrete mixing tub and concrete scoop for the mixing.
3. Bucket of water and rag for cleaning the equipment before and after the test.
4. Curing tank for concrete specimens, see figure 3.2.
5. Ball Mill Machine for grinding the ceramic particles, as shown in figure 3.3.
6. Steel molds to pour the mixture (10cm×10cm×10cm), as shown in figure 3.4.
7. Slump test tools including slump cone, tamping rod, slump plate, and a ruler, as shown in figure 3.5.
8. Oven to dry samples and materials (for water absorption experiment), as shown in figure 3.6.
9. Concrete compression machine (Matest, Italy), see figure 3.7.
10. Infrared thermometer with a range of -60°C to 500°C and a resolution of 0.1°C. In addition, a thermometer couple with a range of 0°C to 250°C was used. The used infrared thermometer and thermometer are shown in figure 3.8.
11. Thermal conductivity measurement device, which was designed and constructed through a separate research project in our university (the program of renewable energy and sustainability) [90]. It is shown in figure 3.9.
12. Heat capacity (specific heat) measurement device, which was designed and constructed through a separate research project at our department (the program of renewable energy and sustainability) [90]. It is shown in figure 3.10.

Figure 3.2: Curing tank for concrete specimens.

Figure 3.3: Los Angeles abrasion ball mill machine.

Figure 3.4: Steel molds for casting concrete specimens.

Figure 3.5: Slump test measurement.

Figure 3.6: Oven to dry samples.

Figure 3.7: Compressive strength measurement device (MATEST).

a. Infrared thermometer. b. Thermometer with couple.

Figure 3.8: Infrared thermometer and thermometer with couple.

Figure 3.9: The hot plate thermal conductivity instrument [90].

Figure 3.10: Foam box for measuring the specific heat capacity of concrete specimens [90].

3.4 Work Procedures

In order to achieve the objective of the project, the following steps were followed.

3.4.1 Raw Material Testing for Conforming to ASTM

All the materials (cement, aggregate and sand) were tested to make sure they conform to ASTM specifications. The raw materials of the concrete mix used in this thesis were tested for identifying the basic physical properties using the tests in table 3.5:

- Sieve analysis test according to ASTM C-136.

- Water absorption and specific gravity test according to ASTM C-127.

- Lose Angles abrasion test according to ASTM C-88.

- Amount of injurious and fines particles according to ASTM D-2419.

Tests results of the raw materials are listed in table 3.5.

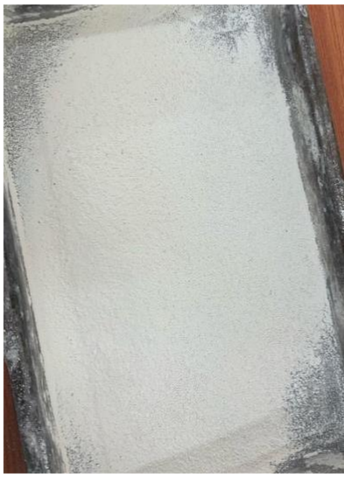
Table 3.5: Materials testing results.

<table>
<tr><td colspan="4" rowspan="2">Type of test</td><td colspan="3" rowspan="2">Standard</td><td rowspan="2">Unit</td><td colspan="5">Result</td></tr>
<tr><td colspan="3">Coarse aggregate</td><td colspan="2">Fine aggregate</td></tr>
<tr><td colspan="4">1. Bulk specific gravity</td><td colspan="3" rowspan="4">ASTM C-127</td><td>-</td><td colspan="3">2.56</td><td colspan="2">2.52</td></tr>
<tr><td colspan="4">2. Specific gravity (Dry-SSD)</td><td>-</td><td colspan="3">2.62</td><td colspan="2">2.64</td></tr>
<tr><td colspan="4">3. Specific gravity (Apparent)</td><td>-</td><td colspan="3">2.72</td><td colspan="2">2.73</td></tr>
<tr><td colspan="4">4. Water absorption</td><td>%</td><td colspan="3">1.02</td><td colspan="2">0.5</td></tr>
<tr><td colspan="4">5. Los Angeles abrasion</td><td colspan="3">ASTM C-88</td><td>%</td><td colspan="3">30.13</td><td colspan="2">-</td></tr>
<tr><td colspan="4">6. Sand equivalent</td><td colspan="3">ASTM D-2419</td><td>-</td><td colspan="3">-</td><td colspan="2">66.11</td></tr>
<tr><td colspan="4">7. Clay lumps and friable particles</td><td colspan="3">ASTM-C142</td><td>%</td><td colspan="3">1.11</td><td colspan="2">-</td></tr>
<tr><td colspan="13">8. Gradation (ASTM C-136)</td></tr>
<tr><td>Sieve No.</td><td></td><td>1"</td><td>3/4"</td><td>1/2"</td><td>3/8"</td><td># 4</td><td># 8</td><td># 16</td><td># 30</td><td># 50</td><td># 100</td><td># 200</td></tr>
<tr><td>Medium aggregate</td><td rowspan="2">Percent Passing</td><td>100</td><td>75</td><td>60</td><td>55</td><td>27</td><td>10</td><td>3.8</td><td>3.4</td><td>2.9</td><td>2.5</td><td>2.3</td></tr>
<tr><td>Fine aggregate</td><td>-</td><td>-</td><td>100</td><td>100</td><td>99</td><td>97</td><td>93</td><td>64</td><td>26</td><td>6.2</td><td>3.8</td></tr>
</table>

3.4.2 Preparation of the Additives

The supplied kaolin, aluminum oxide, chromium oxide were ready for using as additives. The obtained ceramic waste (figure 3.11 a) was crushed using Los Angeles Abrasion Ball Mill Machine (shown in figure 3.3). The powdered sample was then passed through ASTM Mesh #16 (1.18 mm) to achieve uniformly graded sample of the powdered waste as in figure 3.11 b.

a. The ceramic waste before crunching.



b. The ceramic particles after grinding.

Figure 3.11: The ceramic before and after crunching.

3.4.3 Preparation of Concrete and Mix Design

The ingredients were proportioned according to the mix design modified within the building materials laboratory in Palestine Polytechnic University (PPU), which in fact represents the standard mix design of B250. The mix consisted of 306 kg/m^3 cement, 732 kg/m^3 sand, 768 kg/m^3 medium aggregate, and 329 kg/m^3 fine aggregate. All the initial conditions for mixing have been standardized, these included properties of the raw materials, initial concrete mixture temperature, humidity and water to cement (w/c) ratio. This was so that the results are not affected. The independent variables included additive type, addition percentage and curing time. The w/c ratio was set at 0.7. The required amounts of medium aggregate, fine aggregate, sand, cement, water, and additives were weighed in a dry room condition.

For enhanced concrete, four percentage additions, as replacements of cement, were selected to investigate the effects of the investigated additives on the properties of concrete. These include 5%, 10%, 15%, and 20%. The mix designs of control and enhanced concrete specimens are shown in tables 3.6, 3.7, 3.8, and 3.9, for kaolin, the aluminum oxide, the chromium oxide and the ceramic particles, respectively.

Steel molds with (10×10×10) cm^3 dimensions were used conforming to ASTM C470 as shown in figure 3.4. The inside surfaces of molds were coated with oil to prevent the concrete from sticking to the surfaces. In addition, rods were used for compacting, which have a smooth hemispherical tip as specified in ASTM C143. Concrete samples with (10×10×10) cm^3 dimensions were prepared. During this experimental program a total of 300 specimens were casted and tested.

Table 3.6: Mix designs of concrete specimens for investigating the kaolin addition.

Mix	Description	Amount of Concrete Materials					Amount of Kaolin
		Cement	Fine Aggregate	Medium Aggregate	Sand	Water	
		Kg	kg	kg	kg	kg	Kg
Con	control sample	6.12	6.58	15.36	14.64	4.3	0
K5	5 % kaolin as a replacement of cement weight	5.814	6.58	15.36	14.64	4.3	0.306
K10	10 % kaolin as a replacement of cement weight	5.508	6.58	15.36	14.64	4.3	0.612
K15	15 % kaolin as a replacement of cement weight	5.202	6.58	15.36	14.64	4.3	0.918
K20	20 % kaolin as a replacement of cement weight	4.896	6.58	15.36	14.64	4.3	1.224

Table 3.7: Mix designs of concrete specimens for investigating the aluminum oxide addition.

Mix	Description	Amount of Concrete Materials					Amount of Aluminum Oxide
		Cement	Fine Aggregate	Medium Aggregate	Sand	Water	
		Kg	Kg	kg	kg	kg	Kg
Con	control sample	6.12	6.58	15.36	14.64	4.3	0
AO5	5 % aluminum oxide as a replacement of cement weight	5.814	6.58	15.36	14.64	4.3	0.306
AO10	10 % aluminum oxide as a replacement of cement weight	5.508	6.58	15.36	14.64	4.3	0.612
AO15	15 % aluminum oxide as a replacement of cement weight	5.202	6.58	15.36	14.64	4.3	0.918
AO20	20 % aluminum oxide as a replacement of cement weight	4.896	6.58	15.36	14.64	4.3	1.224

Table 3.8: Mix designs of concrete specimens for investigating the chromium oxide addition.

Mix	Description	Amount of Concrete Materials					Amount of Chromium Oxide
		Cement	Fine Aggregate	Medium Aggregate	Sand	Water	
		kg	Kg	kg	kg	kg	Kg
Con	control sample	6.12	6.58	15.36	14.64	4.3	0
CO5	5 % chromium oxide as a replacement of cement weight	5.814	6.58	15.36	14.64	4.3	0.306
CO10	10 % chromium oxide as a replacement of cement weight	5.508	6.58	15.36	14.64	4.3	0.612
CO15	15 % chromium oxide as a replacement of cement weight	5.202	6.58	15.36	14.64	4.3	0.918
CO20	20 % chromium oxide as a replacement of cement weight	4.896	6.58	15.36	14.64	4.3	1.224

Table 3.9: Mix designs of concrete specimens for investigating the ceramic particles addition.

Mix	Description	Amount of Concrete Materials					Amount of Ceramic Particles
		Cement	Fine Aggregate	Medium Aggregate	Sand	Water	
		kg	Kg	kg	kg	kg	Kg
Con	control sample	6.12	6.58	15.36	14.64	4.3	0
CW5	5 % ceramic waste as a replacement of cement weight	5.814	6.58	15.36	14.64	4.3	0.306
CW10	10 % ceramic waste as a replacement of cement weight	5.508	6.58	15.36	14.64	4.3	0.612
CW15	15 % ceramic waste as a replacement of cement weight	5.202	6.58	15.36	14.64	4.3	0.918
CW20	20 % ceramic waste as a replacement of cement weight	4.896	6.58	15.36	14.64	4.3	1.224

Cement was mixed with sand, aggregate (medium and fine) and tap water for 10 min manually using a trowel according to ASTM C172, with following steps:

1. Mix the fine aggregate and cement on a watertight nonabsorbent platform until the mix blends well and becomes uniform in color.

2. Add the medium aggregate and mix it with fine aggregate and cement until the coarse aggregate is evenly distributed throughout the mix.

3. Add water and mix the mixture until the fresh concrete appear to be homogeneous and has a desired consistency.

4. Clean the molds and applying oil to the surfaces.

5. Fill the concrete in the molds in layers approximately 3.33 cm thick each layer. All samples in a set start at the same time and have their layers add at the same time.

6. Compact each layer with not less than 25 strokes per layer using a tamping rod. Each layer rod 25 times in an even pattern. The bottom layer penetrate to the bottom of the mold, and for the layers above it, going through that layer and about a 2.54cm into the layer below it.

7. Level the top surface and smoothen it with a trowel. Tap the outside of the mold with an open hand about 10 to 15 times to remove excess air out of the samples (ASTM C31). A rag is used to clean around the rim of the mold.

8. Label each sample with the number, the date and time.

9. Finally, place it in a protected location free of vibration and disturbances.

The test specimens were stored in a moist air for 24 hours. After that, the specimens were demolded and submerged in fresh water for 24 hours. Finally, the specimens were cured for additional periods of 3, 7, 14, 21 and 28 days in room conditions as shown in figure 3.12.

Figure 3.12: Concrete specimens during curing at room conditions.

3.4.4 Measurement of Slump of Fresh Concrete

Slump test was made on the fresh concrete to measure the effect of additives on the workability. The equipment used for the slump test were corresponded to the specifications mentioned in ASTM C143. The slump test measurement equipment is shown in figure 3.5. The slump tests were conducted according to ASTM C143 as follows:

1. Sample the concrete, first make sure all water has been added according to ASTM C172, and mix it thoroughly.

2. Get a water and moisten the inside of the slump cone and the surface of the slump plate, to keep concrete from sticking at the slump cone.

3. Put the slump cone on the slump plate and clamp it.

4. Fill the first layer to 1/3 of the cone by volume. Rod the layer 25 times with making sure to cover all the surface area inside the cone.

5. Fill the second layer to 2/3 of the cone by volume with making sure that the concrete layer is even and rod it 25 times.

6. Fill the third and last layer up to the top, where the concrete is slightly overflowing and rod it 25 times.

7. Lift the cone straight upwards with no twisting or sideways motion.

8. Flip the cone upside down next to the concrete, and place the tamping rod on top of the cone and over the concrete. Measure the distance from the displaced center to the rod, and then record the slump to the nearest centimeter.

3.4.5 Measurement of Compressive Strength

The device used to determine the compressive strength is MATTES device, which is shown in figure 3.7. The samples were tested by compression testing machine (shown in figure 3.7) after 1day, 3, 7, 14, 21 days curing or 28 days curing according to ASTM C109, as follows:

1. Remove the sample from the water after the specified time, wipe out the excess water from its surface. Check the samples over for defects before set it on the device.

2. Take the dimensions of the sample to the nearest 0.2 meter.

3. Make sure that the bearing surfaces of the device are clean and free of debris.

4. Place the sample in the device.

5. Centrally align the sample on the device base plate. Gently rotate the movable portion by hand so that it touches the top surface of the sample.

6. Apply the load gradually continuously at the rate of 140 $kg/cm^2/min$ and without shock until the sample fails. Load on failure of the cube divided by sample area gives the compressive strength of the concrete, then return the lever to the stop position.

7. Record the maximum load.

Three samples were tested for each age. However, if the compressive strength of any sample varied by more than 15% of the average compressive strength, the results of these sample should be rejected. The average of three samples gave the crushing compressive strength of the concrete.

3.4.6 Measurement of Water Absorption and Density

The pore structure characterization is often investigated by means of a simple test in order to find a very simple compliance standard with respect to the concrete durability. The water absorption test was performed after 28 days according to ASTM C-642 as follows:

1. The specimen was placed in a forced draft oven, the specimen was dried in a temperature of 110 ± 5 °C for 24 hours. After removing the sample from the oven, it was allowed to cool in the dry air to a temperature of 22 ± 3 °C. The sample was weighed and the mass was recorded as W_1.
2. The specimen was immersed on its edge in water at 22 ± 3°C. The specimen was continue soaked in water for 48 hours. The specimen was surface-dried with a towel. The sample was weighed and the mass was recorded as W2.

Then the percentage water absorption was obtained from the following equation:

$$\mathrm{WA} = \frac{\mathrm{W}_2 - \mathrm{W}_1}{\mathrm{W}_1} * 100\% \qquad (3.1)$$

Where WA is the percentage water absorption.

The concrete density (ρ) was determined by dividing the mass of dry sample (W_1) by the specimen volume.

3.4.7 Measurement of Thermal Conductivity

Thermal conductivity of the concrete was measured by means of a steady-state hot plate thermal conductivity method using the device shown in figure 3.9. A well-insulated test room was designed and constructed through a separate research project at our department (the program of renewable energy and sustainability) [90].

A concrete specimen of 1 cm thickness and (10X10) cm^2 cross-sectional area was placed in the test room. A one-dimension heat transfer condition was established. The bottom surface of the concrete specimen was subjected to a uniformly distributed heat source from an electric power supply of 250W. The top surface was allowed to cool by natural convection to the surrounding air. A steady sate heat transfer was achievable within a practical time period of about 90 minutes [90]. Two temperature sensors were used to measure the specimen surface temperature (bottom and top temperatures, T_1 and T_2, respectively). Then, the thermal conductivity (k) was determined according to Fourier's first law of steady state conduction, as follows [91]:

$$k = \frac{Q}{A}\frac{L}{T_1 - T_2} \qquad (3.2)$$

Where Q is the rate of steady state heat transfer determined by the electric power supply, L is the concrete specimen thickness and A is the cross-sectional area of the concrete specimen.

3.4.8 Measurement of Specific Heat (Heat Capacity)

A typical thermal calorimetric method was used for measuring the specific heat using the device shown in figure 3.10. A well-insulated test vessel was designed and constructed through a separate research project at our department (the program of renewable energy and sustainability) [90]. The concrete specimen was placed in a plastic jar within the insulation box to increase the thermal insulation capacity.

A standard cubic concrete specimen (10X10X10) cm^3 with a known mass was used. Prior to testing, the specimen was conditioned at room temperature for at about 24 hours. The initial temperature of the concrete specimen was measured and recorded. A hot water with a recorded temperature of about 50 ^oC was poured in the plastic jar. Then, the specimen was immersed in the hot water, and the insulation box was closed for the required time to reach thermal equilibrium between the specimen and water. One thermometer was inserted in the box to measure the water temperature. A state of thermal equilibrium was achieved with period of about 40-60 minutes [90]. Even though, the test was continued up to 1 hour to ensure the accuracy of readings. A premeasured heat loss to surrounding (equivalent to 1.9 ^oC temperature drop) was compensated for, in the energy balance calculations.

The heat capacity of concrete (c_p) was determined from the measured initial temperature of concrete cool specimen (T_{c1}), initial temperature of hot water (T_{w1}) and the temperature of the final thermal equilibrium state between water and concrete (T_e). It was estimated from energy balance, according to the following equation [91]:

$$c_p = \frac{m_w\, c_{pw}\, (T_{w1} - T_e)}{m_c (T_e - T_{c1})} \qquad (3.3)$$

Where m_w is the mass of water, c_{pw} is the specific heat of water; m_c is the mass of concrete.

The thermal diffusivity (α) was obtained from the measured values of thermal conductivity, specific heat and density, according to its definition as in the following equation [91]:

$$\alpha = \frac{\mathrm{k}}{\rho \mathrm{c_p}} \qquad (3.4)$$

Where k is the thermal conductivity, ρ is the density of concrete specimen and c_p is the heat capacity of concrete.

Chapter Four

Results and Discussion

CHAPTER 4

Results and Discussion

4.1 Introduction

This chapter presents the results, obtained from laboratory testing. Tests were done on fresh and hardened concrete. A discussion on the results is made with reflections on what they may depend on and what they reflect on and with comparing the results with previous finding.

4.2 Thermal Conductivity

The results of thermal conductivity of ceramic waste particles (CWP), kaolin, chromium oxide and aluminum oxide of fully cured samples at 28 days are shown in figure 4.1. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement.

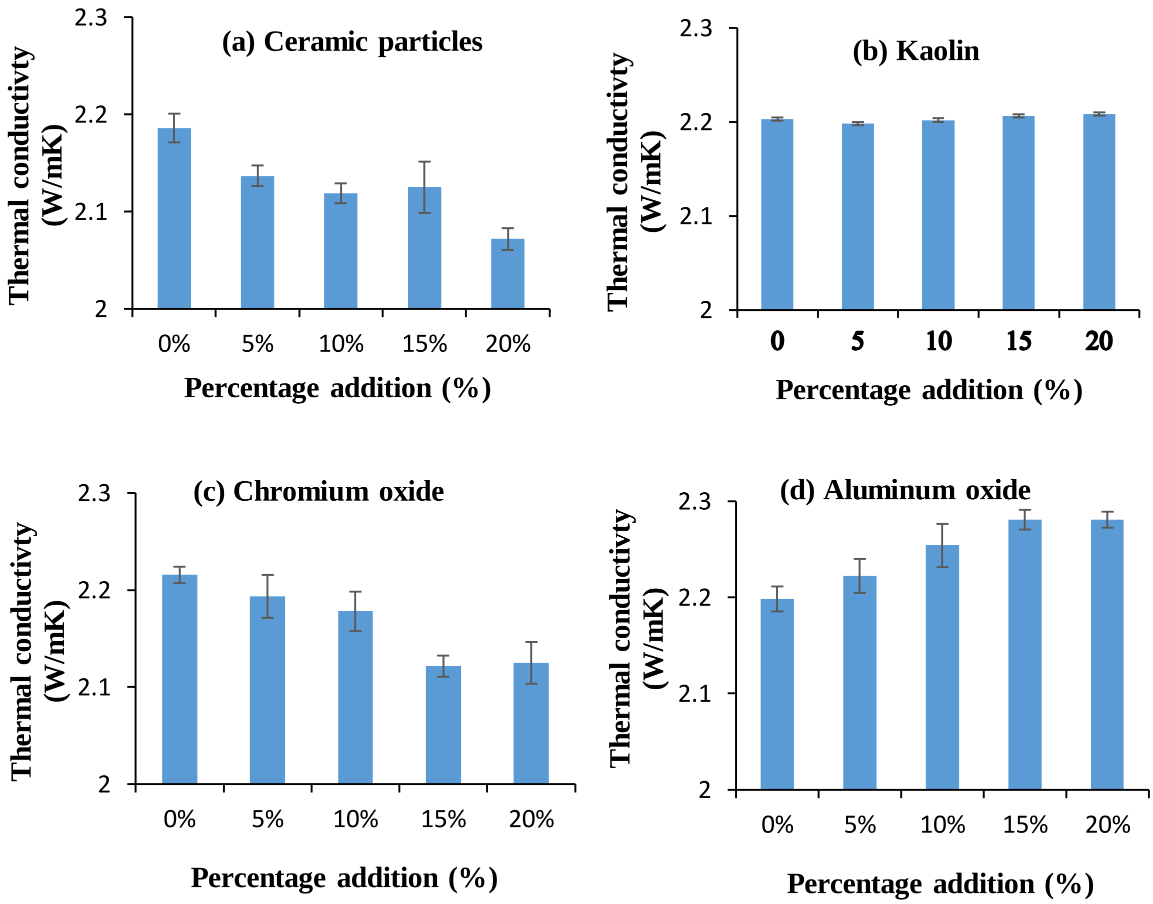


Figure 4.1: Thermal conductivity as functions of percentage additions of (a) ceramic particles, (b) kaolin, (c) chromium oxide and (d) aluminum oxide.

The obtained thermal conductivity of control sample is within the reported range of thermal conductivity for concrete with a mix design of B250 (0.9 to 3.4 W/mK [92, 93]). In fact, the thermal conductivity depends on the bulk density and the moisture content in of concrete. For the ceramic particles, increasing the content of the ceramic particles in the concrete mix decreases the thermal conductivity and thus enhances the thermal insulation. However, the specimens with a percentage of 15% of ceramic particles have a slightly higher thermal conductivity than that with 10% of ceramic particles. These results can be explained by the fact that ceramics are an insulating material with a lower thermal conductivity than concrete. In fact, the addition of CWP resulted in decreasing concrete density as reported in section 4.8. It has been well reported in the literature that the thermal conductivity increases with increasing density [61], see the correlation in eqn.2.5. These results are in agreement with previous findings of the effect of adding ceramic particles in the concrete mix [77, 79]. Vejmelková et al. [77] showed that incorporation of CWP in the concrete as a 10, 20, 40 and 60% cement replacement decreased the thermal conductivity. Pokorny et al. [79] reported that mortar specimens containing 8, 16, 24 and 32% of CWP, as a cement replacement, enhanced the thermal insulation of concrete.

For the chromium oxide, increasing the content of the chromium oxide in the concrete mix decreases the thermal conductivity and thus enhances the thermal insulation. However, the specimens with a percentage of 20% of chromium have a higher thermal conductivity than that with 15% of chromium oxide. These results can be explained by increasing porosity of concrete when adding chromium oxide as a partial replacement of cement. It should be noted that this point has not been studied in the previous literature. It is believed that the addition of chromium oxide has a different mechanism than that of CWP.

The effect of adding kaolin is less significant. Increasing the content of the kaolin in the concrete mixture slightly increases the thermal conductivity. However, modified concrete with 5 and 10% of kaolin as a partial replacement of cement has a lower thermal conductivity than the control samples (without kaolin). These results can be explained by the fact that kaolin contains many compounds in its chemical composition; including a high percentage of conductive oxides, especially that it contains a significant percentage of aluminum oxide.

For the aluminum oxide, increasing the content of the aluminum oxide in the concrete mix increases the thermal conductivity. These results can be explained by that aluminum oxide is a conductive material whose thermal conductivity value is very high compared to the cement. It should be noted that this subject has not been studied in the previous literature. Comparison of thermal conductivity results shown in figure 4.1 indicates that the lowest value is 2.07 W/mK when utilizing 20% ceramic particles as a partial replacement of cement. Followed by 2.12 W/mK when utilizing 15% chromium oxide and when utilizing 10% ceramic particles.

4.3 Specific Heat (Heat Capacity)

The results of specific heat of ceramic particles, kaolin, chromium oxide and aluminum oxide of fully cured samples at 28 days are shown in figure 4.2. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement.

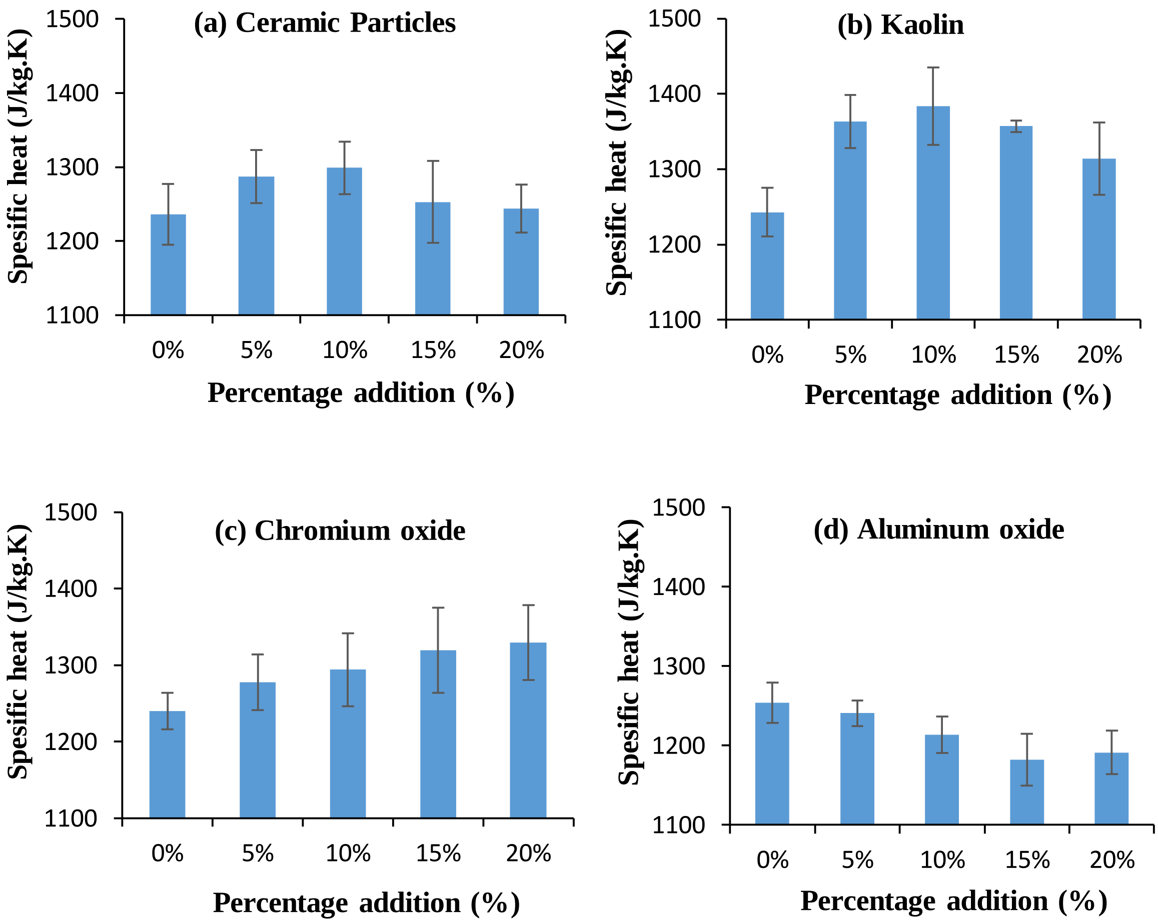


Figure 4.2: Specific heat results for (a) ceramic particles, (b) kaolin, (c) chromium oxide, (d) aluminum oxide.

The obtained specific heat capcaity of control sample is within the reported range of specific heat capcaity for concrete with a mix design of B250 (840 J/kg.K to 1800 J/kg.K [94]). For the ceramic particles, it is noted from the above figure that the specific heat value increases with the using of 5 and 10% of ceramic particles by weight of the cement in the concrete mix. However, the specific heat value decreases after that with the using of 15 and 20% of ceramic particles. For the kaolin, it is noted from the above figure that the specific heat value increases with the using of 5 and 10% of kaolin by weight of the cement in the concrete mix. However, the specific heat value decreases after that with the using of 15 and 20% of kaolin by weight of the cement in the concrete mix.

For the chromium oxide, the specific heat value increases with the addition of chromium oxide. For the aluminum oxide, the specific heat value decreases for the addition of aluminum oxide. However, the percentage of 20% of aluminum oxide has a higher specific heat value than the 15% of aluminum oxide. It should be noted that the specific heat of the concrete using ceramic particles, kaolin, chromium oxide and aluminum oxide as a partial replacement of cement has not been studied in the previous literature. However, comparison of specific heat results shown in figure 4.2 indicates that the higher value is 1383 J/kgK when utilizing 10% kaolin as a partial replacement of cement in concrete mix. From the other side, 15% replacement of cement using aluminum oxide has the lowest value of specific heat, which is 1182 J/kgK.

4.4 Thermal Diffusivity

The results of thermal diffusivity of ceramic particles, kaolin, chromium oxide and aluminum oxide of fully cured samples at 28 days are shown in figure 4.3. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement.

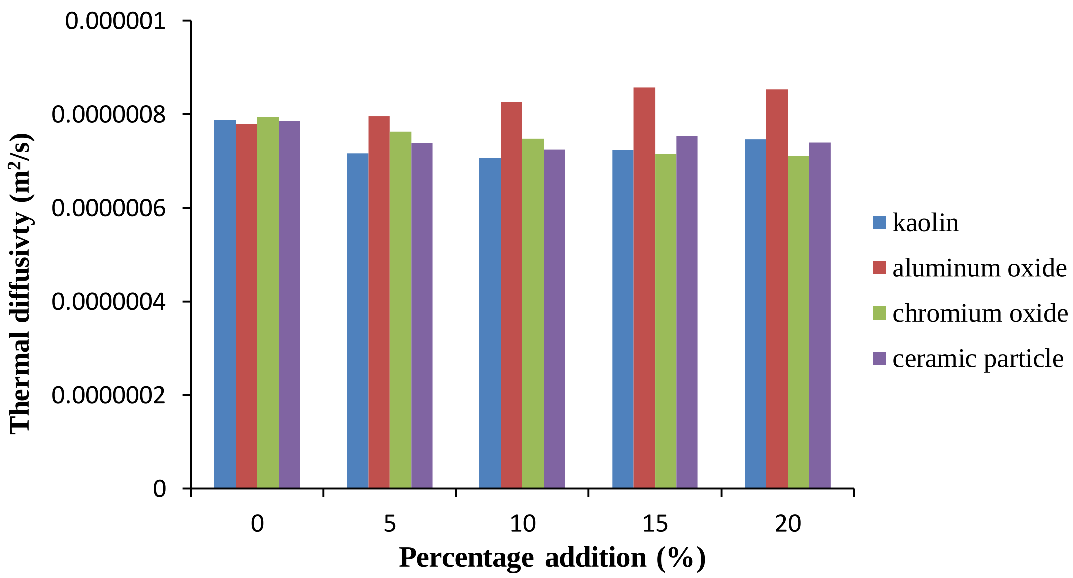


Figure 4.3: Thermal diffusivity results of the all additives.

In general, it is noted from figure 4.3 that with the kaolin and the ceramic particles, the thermal diffusivity value decreases with the using of 5 and 10% of the additive by weight of the cement in the concrete mix. However, the thermal diffusivity value increases after that with the using of 15 and 20% of the kaolin, but for ceramic particles, the thermal diffusivity value decreases after that with the using of 15% and after that increases with the using of 20%.

From the other side, it is noted that the thermal diffusivity value increases for the addition of aluminum oxide. However, the percentage of 20% of aluminum oxide has a lower thermal diffusivity value than the 15% of aluminum oxide. In addition, the thermal diffusivity value decreases for the addition of chromium oxide. However, comparison of thermal diffusivity results shown in the figure 4.3 indicates that the higher value was when utilizing 15% aluminum oxide as replacement cement. From the other side, 10% replacement cement of kaolin had the lowest value of thermal diffusivity. These results are the result of the thermal diffusivity equation 3.4.

4.5 Compressive Strength

The results of compressive strength are divided into two sections. The first section is compressive strength results for the percentages of 0 and 10% of each additive after 1 day, 3, 7, 14, 21 and 28 days. The second section is compressive strength results of fully cured samples of all additives at 28 days.

4.5.1 Development of Compressive Strength with Curing Age

Figure 4.4 shows the results of the development of compressive strength of ceramic particles, kaolin, chromium oxide and aluminum oxide for specimens with 10% additions as partial replacements of cement at 1 day, 3, 7, 14, 21 and 28 days. The curves are also compared to that for a control sample of B250.

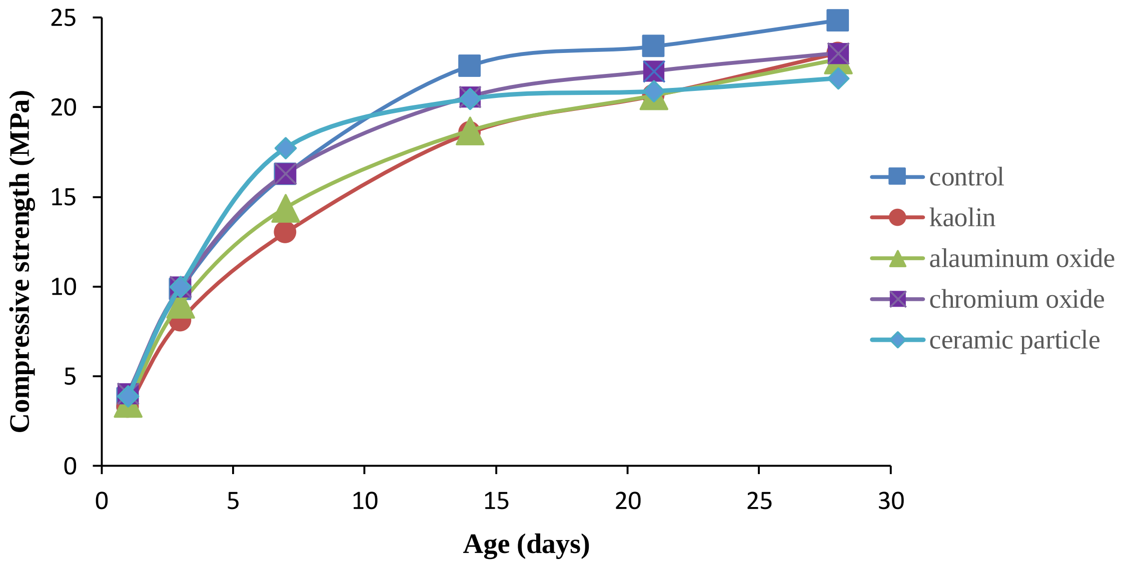


Figure 4.4: Compressive strength results of the all additives with age.

The compressive strength of the fully cured control samples is close to the values indicated in the table 2.2 (22.5-27.5MPa).

For control samples, the obtained curve of the relationship between compressive strength and the age of the sample in days is a logarithmic curve. These results are reasonable and acceptable when compared to the standard results presented in the table 2.2.

For the ceramic particles, the curve of the relationship between compressive strength and the age of the sample in days is a logarithmic curve. The samples are faster than the control samples.

For the chromium oxide, the curve of the relationship between compressive strength and the age of the sample in days was a logarithmic curve. The samples are faster than the control samples.

For the kaolin, the curve of the relationship between compressive strength and the age of the sample in days was a logarithmic curve. The samples are slower than the control samples.

For the aluminum oxide, the curve of the relationship between compressive strength and the age of the sample in days was a logarithmic curve. The samples are slower than the control samples.

Table 4.1 shows the compressive strength percentage that the modified concrete reaches each day of the compressive strength of the cured concrete after 28 days.

Table 4.1: The compressive strength percentage that the modified concrete reaches each day of the compressive strength of the cured concrete after 28 days.

Day	Control	Ceramic	Chromium Oxide	Kaolin	Aluminum Oxide
1	15	18	17.6	14.3	15.4
3	40	46.3	43.3	35.3	39.9
7	65.4	82	70.8	56.5	63.5
14	89.8	94.7	89.5	80.7	82.5
21	94.1	96.7	95.6	89.7	91.1
28	100	100	100	100	100

4.5.2 Compressive Strength of Fully Cured Concrete

The results of compressive strength of ceramic particles, kaolin, chromium oxide and aluminum oxide of fully cured samples at 28 days are shown in figure 4.5. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement.

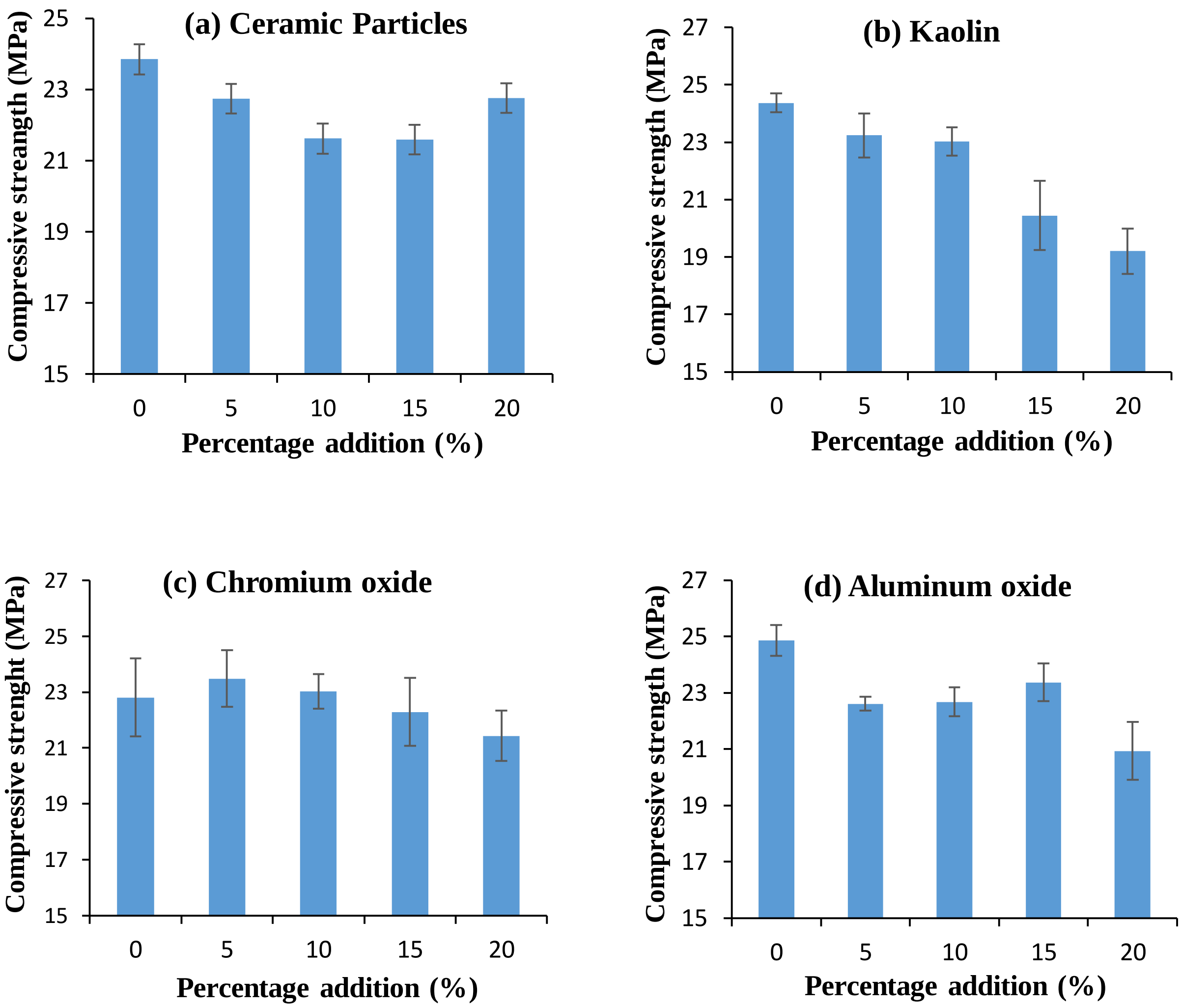


Figure 4.5: Compressive strength results for (a) ceramic particles, (b) kaolin, (c) chromium oxide, (d) aluminum oxide.

The compressive strength decreases for the addition of the ceramic particles, the chromium oxide, the kaolin and the aluminum oxide. For the ceramic particles, this result is logical and corresponds to what is found in the previous literature [78-80], which showed that the compressive strength of the concrete decreases when using ceramic in the concrete mix. It should be noted that the compressive strength of the concrete using chromium oxide and aluminum oxide has not been studied in the previous literature. For the kaolin, this result is corresponds to what is found in the previous literature [84], which showed that the compressive strength of the concrete decreases when using kaolin in the concrete mix.

All these results are logical and can be explained by the concept of cement as the adhesion substance that gives strength to the concrete mixture, so it was natural that these additives reduce the value of the compressive strength of concrete when added as a partial alternative to cement. The highest compressive strength value achieved was the control mix. This is due to the relatively high cement content in the mix. As the amount of the additives decreases gradually, the compressive strength decreases for 28-day. While the results in figure 4.5 might indicate that, the additives may act as filler instead of a binder/pozzolane material. The decrease in the compressive strength may be attributed to the reduction in the cement binder content and the very low slump, which will apparently affect its conformability. The compressive strength decreases as the proportion of the additives in the concrete increases. In the early curing stages, pozzolan acts only as a filler and does not undergo a pozzolanic reaction. The decrease in early compressive strength is mainly because of the immature pozzolanic reaction in concrete and the protective growth of the component-affected C-S-H gel in the ground ceramic powder.

Comparison of compressive strength results shown in the figure 4.5 indicates that the optimum value is 23.5 MPa when utilizing 5% chromium oxide as a partial replacement of cement in the concrete mix. Followed by 23.37 MPa when utilizing 15% aluminum oxide, followed by 23.24 MPa when utilizing 5% kaolin. After that, 23.03 MPa is coming when utilizing 10% chromium oxide and 23.02 MPa when utilizing 10% kaolin. Followed by 22.77 MPa when utilizing 20% ceramic particles. Followed by 22.74 MPa when utilizing 5% ceramic particles, followed by 22.67 MPa when utilizing 10% aluminum oxide and followed by 22.61 MPa when utilizing 10% aluminum oxide. As for the rest of the values, it is less than what is allowed according to the standard ASTM.

4.7 Water Absorption of Fully Cured Concrete

The results of water absorption of ceramic particles, kaolin, chromium oxide and aluminum oxide of fully cured samples at 28 days are shown in figure 4.6. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement.

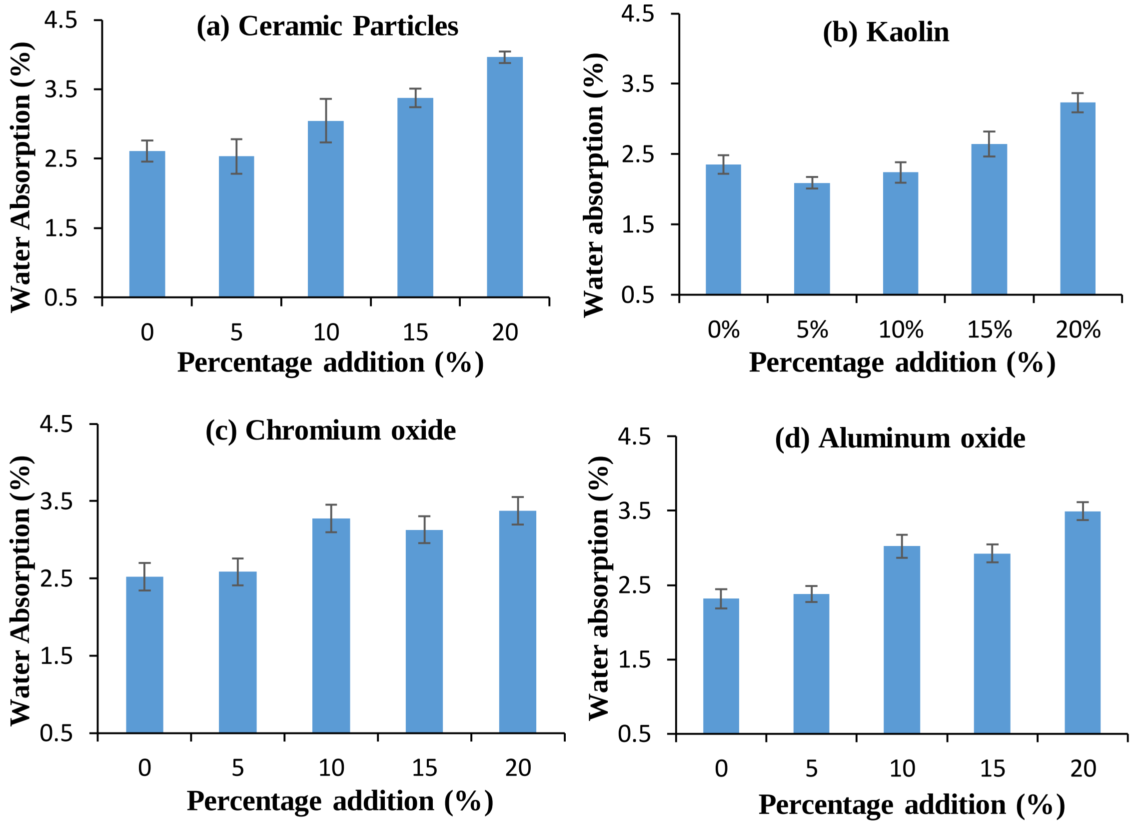


Figure 4.6: Water absorption results for (a) ceramic particles, (b) kaolin, (c) chromium oxide, (d) aluminum oxide.

The water absorption of the fully cured control samples is close to the values indicated in the table 2.2 (2-5%).

For the ceramic particles, generally it is noted from the above figure that the greater the ceramic particles content in the concrete mixture, the greater the water absorption. However, the percentage of 5% of ceramic particles of cement weight in the concrete mix has a lower water absorption value than the control sample (without ceramic particles). For the chromium oxide, generally it is noted from the above figure that the greater the chromium oxide content in the concrete mixture, the greater the water absorption. However, the percentage of 15% of chromium oxide from cement weight in the concrete mixture has a lower water absorption than the 10% of chromium oxide. For the kaolin, generally it is noted from the above figure that the greater the kaolin content in the concrete mixture, the greater the water absorption ratio. However, the percentage of 5 and 10% of kaolin from cement weight in the concrete mixture has a lower water absorption than the control sample. For the aluminum oxide, generally it is noted from the above figure that the greater the aluminum oxide content in the concrete mixture, the greater the water absorption. However, the percentage of 15% of aluminum oxide from cement weight in the concrete mixture has a lower water absorption than the 10% of aluminum oxide.

All of these results are logical and can be explained where Guneyisi et al. [96] noted that there is a relationship between the absorbance and the mechanical performance of concrete mixes, the higher the mechanical strength of the concrete, the lower the absorbance value. These results are consistent with those of this study. However, 5% replacement cement of kaolin has the lowest value of water absorption 2.1%, followed by 10% Kaolin ratio with 2.2% water absorption. From the other side, the highest water absorption value was 3.96% when utilizing 20% ceramic particles, followed by 3.49% when utilizing 20% aluminum oxide.

4.7 Slump of Fresh Concrete

The results of slump of fresh concrete with ceramic particles, kaolin, chromium oxide and aluminum oxide samples at 28 days are shown in figure 4.7. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement, which had attained the slump of 80- 190 mm.

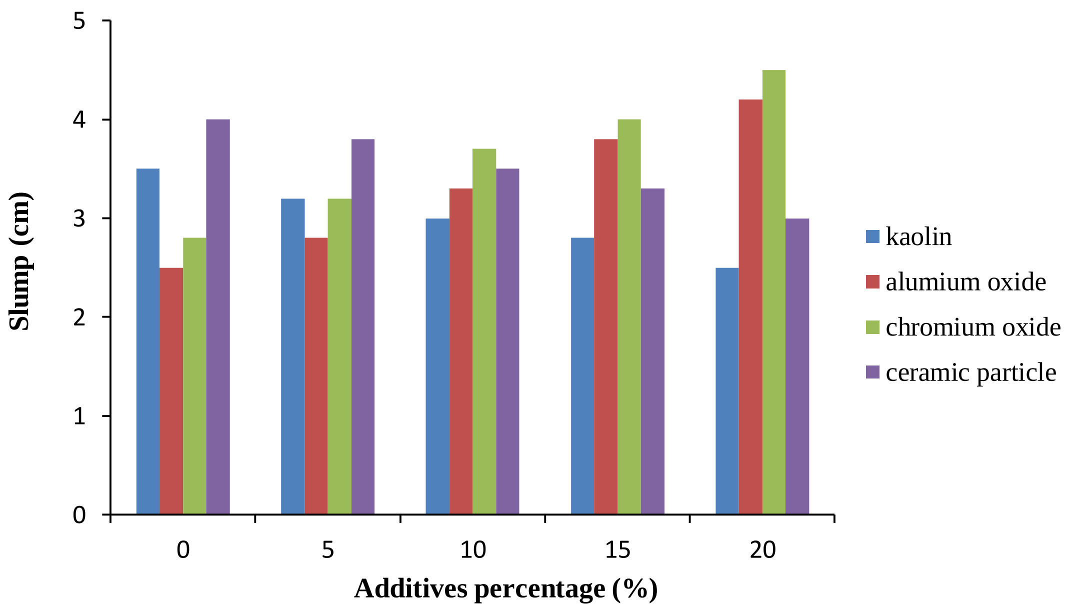


Figure 4.7: Slump tests results of the all additives.

The slump of the fresh control samples is close to the values indicated in the table 2.2 (25-100cm).

For the ceramic particles and the kaolin, the slump decreases gradually for the addition of ceramic particles and kaolin. For the ceramic particles, this results are corresponds to what was found in the previous literature [79,80], which showed that the slump of the concrete decreases when using ceramic in the concrete mix.

For the kaolin, this results are corresponds to what was found in the previous literature [84] which showed that the slump of the concrete decreased when using kaolin in the concrete mix. This can

+6 be attributed to the higher specific surface area of ceramic particles and kaolin compared with that of cement, which is about 1.5 times more than that of cement. This can be attributed to the fact that ceramic particles and kaolin have a very limited instantaneous hydraulic reaction due to their very low calcium oxide content.

For the chromium oxide and the aluminum oxide, the slump increases gradually with the addition of the chromium oxide and the aluminum oxide. It should be noted that the slump of the concrete using chromium oxide and aluminum oxide has not been studied in the previous literature.

Comparison of slump tests results shown in figure 4.7 indicates that the highest slump value is 4.5 cm when utilizing 20% chromium oxide of the cement weight in the concrete mix. From the other side, the lowest slump value was 2.5 cm when utilizing 20% kaolin.

4.8 Density of Fully Cured Concrete

The results of density of fully cured samples at 28 days with ceramic particles, kaolin, chromium oxide and aluminum oxide are shown in figure 4.8. The investigated percentage additions are 0, 5, 10, 15 and 20% as partial replacements of cement.

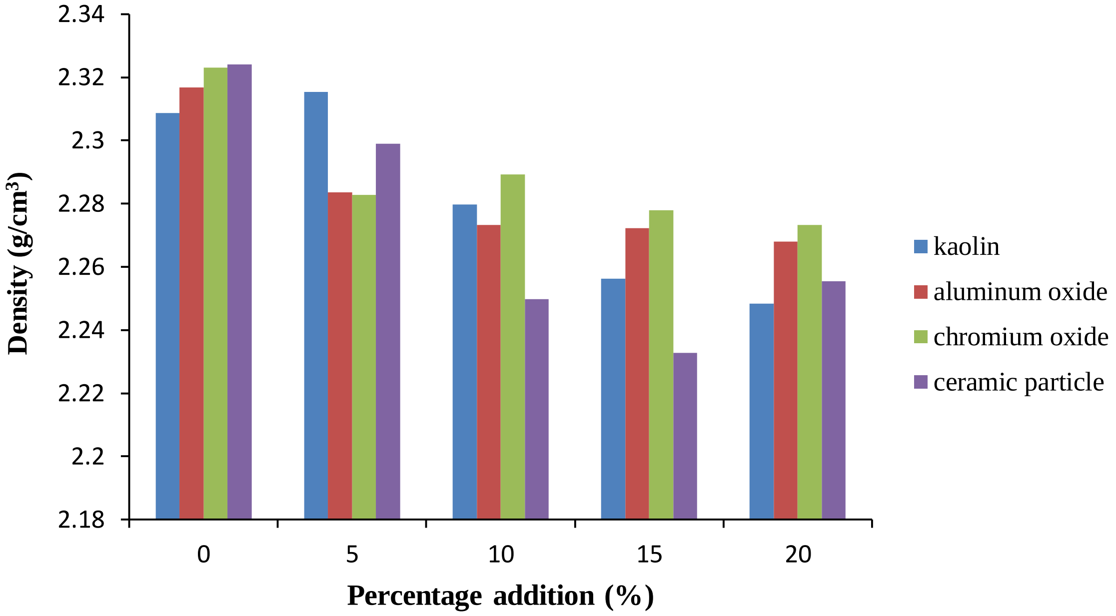


Figure 4.8: Density results of the all additives.

The density decreases for the addition of the ceramic particles, the chromium oxide, the kaolin and the aluminum oxide. This leads to conclude that the water absorption will increase as the amount of they in the mix increases. However, the percentage of 20% of ceramic particles in the concrete mix as a partial replacement of cement has a lower density value than the 10 and 15% of ceramic particles. This results are corresponds to what was found in the previous literature [79, 80], which showed that the density of the concrete decreases when using ceramic in the concrete mix. The percentage of 10% of chromium oxide in the concrete mix has a higher density value than the 5% of chromium oxide. The ratio of 5% of kaolin from cement weight in the concrete mixture has a higher density value than the control sample (without kaolin). All these results are logical, and we have seen a reflection on the results of water absorption.

However, 15% replacement of cement using ceramic particles has the lowest value of density 2.23, followed by 20% Kaolin ratio and 10% ceramic particles with 2.25 density. From the other side, the highest density value was 2.32 when utilizing 5% Kaolin, followed by 2.3 when utilizing 5% ceramic particles.

Finally, when applying equation 2.5 to the density values we obtained, we found that the thermal conductivity values corresponded roughly to the equation.

4.9 Energy Saving in building

Energy efficient buildings are designed to use the least amount of energy. Buildings can be made energy efficient by using ceramic particles in concrete, which helps reduce heat loss. The replacement percentage of 20% ceramic is chosen as a substitute for cement for making a simulation on a specific building. This is done because its addition gives the lowest value of the thermal conductivity while maintaining acceptable other concrete properties. The program used to do the simulation is the Excel program.

High-quality design is prerequisites in energy-efficient building. Minimizing thermal conductivity is the key in this section, which is shown the calculation of heat transfer and heating-cooling load in a residential building, and study the effect of using ceramic particles in heating load and energy consumption to compare between using ceramic particles and without using ceramic particles in concrete walls.

In order to calculate the temperatures and heating or cooling loads of a building, one has to construct a mathematical model of the heat transfer phenomenon in the building. This model can be very simple. On the other hand, a very complex model can be used containing hundreds of differential equations and paired nonlinear equations. It is almost impossible to make a complete model of all the details involved in a building. Not only because of the complex calculations this will lead to, but also because many of the parameters necessary for a complete model are somewhat unknown. To overcome some of these issues, current models often use one or more of the following assumptions.

- A uniform air temperature in every room / area.
- Uniform surface temperature on each wall or part of it.
- One-dimensional heat transfer in every wall or part of the wall.
- A diffuse distribution of solar radiation inside the rooms.
- All heat transfer processes are treated as a linear phenomena.

Figure 4.9 displays the elevations of a house in Hebron –Palestine and figure 4.10 illustrates the sketch plane of the house.

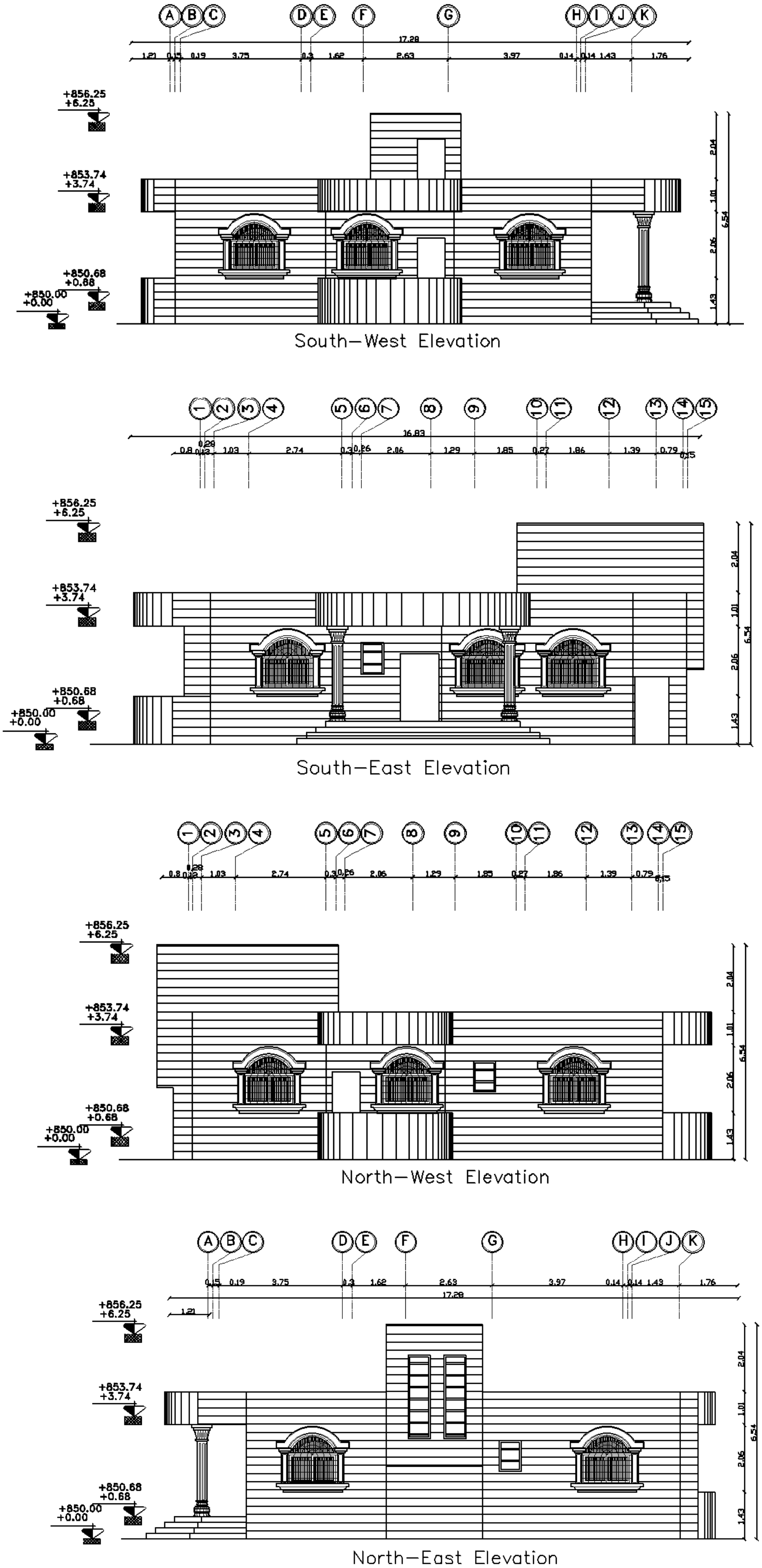


Figure 4.9: Elevations of a house in Hebron –Palestine.

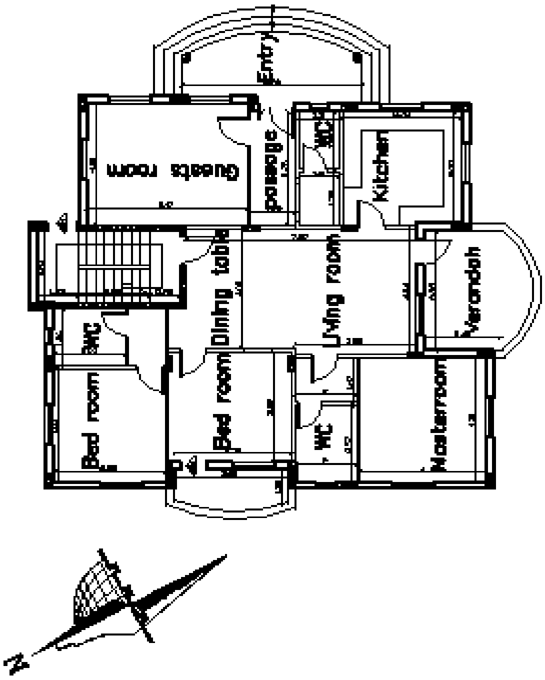


Figure 4.10: Sketch plane of a house in Hebron –Palestine with area=197 m square.

Table 4.2 illustrates the types of heat transfer in the building. Table 4.3 displays the specifications of the building used and table 4.4 shows the weather specifications.

Table 4.2: The three mode of heat transfer convection, radiation and conduction.

Heat transfer	Transient at home
Conduction	Wall, windows, doors, floor, ceiling.
Convection	Air and outside boarder of home.
Radiation	Sunlight on wall and ceiling, windows and doors, human body, heater, electrical equipment, lighting.

Table 4.3: Residential building specifications.

Location	Hebron –Dura
Area	197 m^2
Wind speed	0.5-5 m/s
Type	Residential
No. of persons	6
R_{in}	0.12 m^2°C/W
R_{out}	0.06 m^2°C/W

Table 4.4: Weather specification.

T_{in}	20°C
$T_{out, summer}$	33°C
$T_{out, winter}$	4°C
H_{in}	5 W/m^2°C
H_{out}	30 W/m^2°C

The following equations was used for calculating the cooling and heating load [91]:

$$Q = \frac{(T_i - T_o)}{R_{total}} \tag{4.1}$$

$$R_{(conduction)} = \frac{L}{kA} \tag{4.2}$$

$$R_{(convection)} = \frac{1}{h\ A_{surface}} \tag{4.3}$$

$$R_{total} = R_{(conduction)} + R_{(convection)} \tag{4.4}$$

Where Q is the amount of heat transfer, T_i is the indoor temperature, T_o is the outdoor temperature, R_{total} is the total thermal resistance, L is the thickness, $R_{(conduction)}$ is the thermal resistance by conduction, $R_{(convection)}$ is the thermal resistance by convection, h is the convection heat transfer coefficient and $A_{surface}$ is the surface area.

The heating load is the amount of thermal energy that must be added to a space to keep the temperature within an acceptable range. The cooling load is the amount of thermal energy that must be removed from a place (cooling) to keep the temperature within an acceptable range.

Table 4.5 displays the thermal conductivity of the wall, ceiling and floor layers in the building. Table 4.6 shows the details of the building elevations.

Table 4.7 shows the heating and cooling load demand for the residential building for the control concrete (B250) and by using 20% ceramic particles replacement by weight of cement in the concrete mix with using the hollow concrete blocks (HCB) in walls layers.

From the other side, table 4.8 displays the heating and cooling load demand for the residential building for the control concrete (B250) and by using 20% ceramic particles replacement by weight of cement in the concrete mix without using the hollow concrete blocks (HCB) in walls layers.

Table 4.9 displays the heating and cooling load demand for the building for B250 concrete and 20% ceramic particles replacement by weight of cement without using the hollow concrete blocks (HCB) in walls layers.

Table 4.5: Thermal conductivity of the wall, ceiling and floor layer.

Layer	Tickness	k ($W/m^{2o}C$)
Wall layers		
Plaster	0.02	0.18
Hollow block	0.07	0.21
Insulation	0	0.052
Plain concrete	0.15	2.2
Stone (MOFAJAR)	0.05	1.4
Floor layers		
Terazzo	0.03	1
Mortar	0.02	0.8
Sand	0.09	0.3
RC floor slab	0.1	1.17
Polythylene sheet dam	0.01	0.19
Base coure	0.2	1.48
Ceiling layers		
Terazzo	0.03	0.84
Mortar	0.03	0.8
Sand	0.07	0.3
Ribbed floor	0.25	0.21
Plaster with paint	0.02	0.18
R_i R_o		
Floor R_i		0
Floor R_o		0
Cailing R_i		0.31
Ceiling R_o		0.05

Table 4.6: The details of the building elevations.

Detail	S-W elevation	S-E elevation	N-E elevation	N-W elevation
$T_i - T_o$ (°C)	16	16	16	16
Area of walls (m^2)	42.5	37.7	41.9	44.5
R_{th} of walls	1.5	1.5	1.5	1.5
No. of windows	3	3	5	4
Area of windows (m^2)	5.6	4.3	6.6	6.2
Type of windows	Double glass 6/3/6	Double glass 6/3/6	Double glass 6/3/6	Double glass 6/3/6
k of windows ($W/m^{2o}C$)	0.8	0.8	0.8	0.8
R_{th} of windows	20.8	20.8	20.8	20.8
No. of doors	1	2	0	1
Area of doors (m^2)	1.7	3.4	0	1.7
Type of doors	Steel	Steel		Steel
k of doors ($W/m^{2o}C$)	2.7	2.7		2.7
R_{th} of doors	0.1	0.1		0.1

Table 4.7: The heating and cooling load demand for the residential building with using the hollow concrete blocks (HCB) in walls layers.

Elevation	Heating Load - Control (W)	Heating load - with 20% CWP (W)	Cooling load - Control (W)	Cooling load - with 20% CWP (W)
S-W elevation walls	748	645	608	505
S-E elevation walls	663	561	539	437
N-E elevation walls	738	635	599	497
N-W elevation walls	783	680	636	534
Ceiling	1463	1463	1463	1463
Floor	2865	2865	835.24	835
Windows				
W/ S-W elevation	4.3	4.3	3.5	3.5
W/ S-E elevation	3.3	3.3	2.7	2.7
W/ N-E elevation	5.1	5.1	4.1	4.1
W/ N-W elevation	4.7	4.7	3.9	3.9
Doors				
D/ S-W elevation	245	245	199	199
D/ S-E elevation	490	490	398	398
D/ N-W elevation	245	245	199	199
Total	8257	7846	5491	5081

Table 4.8: The heating and cooling load demand for the residential building without using the hollow concrete blocks (HCB) in walls layers.

Elevation	Heating Load - Control (W)	Heating load - with 20% CWP (W)	Cooling load - Control (W)	Cooling load - with 20% CWP (W)
S-W elevation walls	1181	1066	960	831
S-E elevation walls	1048	946	851	714
N-E elevation walls	1165	1035	946	820
N-W elevation walls	1237	1139	1005	868
Ceiling	1463	1463	1463	1463
Floor	2865	2865	835	835
Windows				
W/ S-W elevation	4.3	4.3	3.5	3.5
W/ S-E elevation	3.3	3.3	2.7	2.7
W/ N-E elevation	5.1	5.1	4.1	4.1
W/ N-W elevation	4.7	4.7	3.9	3.9
Doors				
D/ S-W elevation	245	245	199	199
D/ S-E elevation	490	490	398	398
D/ N-W elevation	245	245	199	199
Total	9955	9512	6870	6341

Table 4.9: The heating and cooling load demand for the building for B250 concrete and 20% ceramic particles replacement by weight of cement without using the hollow concrete blocks (HCB) in walls layers.

Control	Q (kW)	COP	P (kW)	T/day (h)	E/day (kWh)	Cost/day (NIS)	Cost/day (NIS)	Cost/month (NIS)
Heating load	9.955	3.5	2.8	8	22.7	0.55	12.5	375
Cooling load	6.87	3.3	2.1	8	16.6	0.55	9.1	273
20% Cr	Q (kW)	COP	P (kW)	T/day (h)	E/day (kWh)	Cost/day (NIS)	Cost/day (NIS)	Cost/month (NIS)
Heating load	9.512	3.5	2.7	8	21.6	0.55	11.9	356
Cooling load	6.341	3.3	1.9	8	15.5	0.55	8.5	255

By using 20% ceramic particles by replacement of cement, for cooling load, the cost saving per month is 19 Nis. For heating load, the cost saving per month is 18 Nis.

Note: The effect of radiation has not been studied when running the simulations.

Chapter Five

Conclusions and Recommendations

Chapter 5

Conclusions and Recommendations

5.1 Introduction

This chapter summarizes the conclusions. This chapter gives a summary of thesis and lists the findings of this research; some general conclusions are made to summarize the work. Conclusions are made on the experimental work, calculations, results, comparisons, and analysis. Possible further research areas complementing this thesis are also included in this chapter.

5.2 Conclusions

Based on the results and analysis done as a part of this research thesis, the followings are concluded:

- **For Ceramic Particles**

1. The thermal conductivity of modified concrete decreases with increasing percentage addition.
2. The heat capacity of modified concrete increases with increasing percentage addition.
3. The compressive strength of the modified concrete decreases with increasing percentage addition, while the percentages additions of 5 and 20 give acceptable values of the compressive strength.
4. Water absorption increases with increasing percentage addition.
5. The slump decreases with the increase in the percentage addition of ceramic particles in the mix.
6. The density decreases with increasing percentage addition. However, the percentage addition of 20% of ceramic particles in the concrete mix has a lower density value than that of 10 and 15% of ceramic particles.

- **For Chromium Oxide**

1. The thermal conductivity of modified concrete decreases with increasing percentage addition.
2. The heat capacity of modified concrete increases with increasing percentage addition.

3. The compressive strength of the modified concrete decreases with increasing percentage addition, while the percentages additions of 5, 10, 15 and 20 give acceptable values of the compressive strength.
4. The water absorption increases with increasing percentage addition.
5. The slump increases with the increase in the percentage addition in the mix.
6. The density decreases with increasing percentage addition. However, the percentage addition of 10% of chromium oxide in the concrete mix has a higher density value than that of 5%.

- **For Kaolin**

1. The thermal conductivity of modified concrete decreases with 5 and 10 percentage additions and increases with 15 and 20% percentage additions.
2. The heat capacity of modified concrete decreases with 5 and 10 percentage additions and increases with 15 and 20% percentage additions.
3. The compressive strength of the modified concrete decreases with increasing percentage additions, but the percentages additions of 5 and 10 give acceptable values of the compressive strength.
4. The water absorption decreases with 5-percentage addition. After that, it increases with increasing kaolin percentage addition in the concrete mix.
5. The slump decreases with the increase in the percentage addition in the mix.
6. The density decreases with increasing percentage addition. However, the percentage addition of 5% of kaolin of cement weight in the concrete mix has a higher density value than that of the control sample.

- **For Aluminum Oxide**

1. The thermal conductivity of modified concrete increases with increasing percentage addition.
2. The heat capacity of modified concrete decreases with increasing percentage addition.
3. The compressive strength of the modified concrete decreases with increasing percentage addition, but the percentages additions of 5, 10 and 15 give acceptable values of the compressive strength.
4. The water absorption increases with increasing percentage addition.
5. The slump increases with the increase in the percentage addition in the mix.
6. The density decreases with increasing percentage addition.

Overall Conclusions

These is a strong evidence that kaolin, aluminum oxide, chromium oxide and ceramic particles can be potential additions in producing environmental friendly concrete.

For **thermal conductivity**, comparison of thermal conductivity results shown in the previous chapter indicates that the best value of thermal conductivity is 2.07 W/mK when utilizing 20% ceramic particles as a partial replacement of cement in the concrete mix. Followed by 2.12 W/mK when utilizing 15% chromium oxide and when utilizing 10% ceramic particles.

Based on the comparison of **compressive strength** results, the optimum value was 23.5 MPa when utilizing 5% chromium oxide as a partial replacement of cement in the concrete mix, followed by 23.37 MPa when utilizing 15% aluminum oxide. After that 23.24 MPa is coming when utilizing 5% kaolin, followed by 23.03 MPa when utilizing 10% chromium oxide and 23.02 MPa when utilizing 10% kaolin.

For **water absorption**, 5% replacement of cement using kaolin has the optimum value of water absorption 2.1%, followed by 10% Kaolin with 2.2% water absorption and followed by 5% aluminum oxide with 2.38% water absorption.

For **specific heat**, comparison of specific heat results indicates that the higher value is 1383 J/kgK when utilizing 10% kaolin as a partial replacement of cement in concrete mix. From the other side, 15% replacement of cement using aluminum oxide has the lowest value of specific heat, which is 1182 J/kgK.

For **slump**, comparison of slump tests results indicates that the highest slump value is 4.5 cm when utilizing 20% chromium oxide of the cement weight in the concrete mix. From the other side, the lowest slump value was 2.5 cm when utilizing 20% kaolin.

The model calculations indicate that a saving of about 8% of energy used for heating and cooling can be achieved when ceramic waste particles are used at 20% percentage addition, as a replacement of cement, for concrete of walls for a particular residential building.

Finally, this study shows promising results of utilizing kaolin, aluminum oxide, chrome oxide and ceramic particles as additives for improving concrete characteristics. This project will open new approaches for investees to give more attention on these additives as available resources.

5.3 Recommendations

Application recommendations include the followings:

1. Since the addition of high ratio of kaolin, aluminum oxide, chromium oxide and ceramic particles decreases compressive strength, it is recommended to use kaolin, aluminum oxide, chromium oxide and ceramic particles for non-structural Portland cement concrete in buildings such as floor slabs, floor ribs, underground slabs, behind building stones and in partitions etc.
2. It is recommended to use low ratio of kaolin, aluminum oxide, chromium oxide and ceramic particles in the structural concrete, since the compressive strength will be within an acceptable range, while a good thermal insulation can be achieved.

Recommendations for future research work include the followings:

1. It is recommended to study the effect of larger sizes of ceramic particles on concrete.
2. It is recommended to investigate the effects of these mineral additives on other physical characteristics of concrete such as shrinkage limit, permeability etc.
3. It is recommended to explore the effect of other raw materials in these mixes and study the effects of additives on physical characteristics.
4. It is recommended to investigate the effects of these mineral additives on the durability, soundness and permeability of the concrete on the long term. These characteristics are important to evaluate the performance of the concrete in the long run.
5. It is recommended to study the possibility of using more than one of these additives together as alternatives to cement and the effect of this combination on the different properties of concrete.
6. It is recommended to study the possibility of using these materials with other materials of good properties and study the effect of this combination on the different properties of concrete.
7. It is recommended to study the effect of water to cement ratio on the different properties of concrete for modified concrete with these mineral additives.
8. It is recommended to develop the simulation in the future.

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