Cairo University

MECHANICAL PROPERTIES AND DURABILITY OF SYNTHESIZED GEOPOLYMER COMPOSITES BASED ON METAKAOLIN AND OTHER BY-PRODUCT MATERIALS

By

Eslam Ahmed Ahmed Mahmoud El-Gabry

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
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in
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

Mechanical properties and durability of synthesized geopolymer composites based on metakaolin and other by-product materials

Key Words:
Cement Kiln Dust; Slag; Metakaolin; Geopolymer Concrete; Compressive strength

Summary:

In this research, 19 different synthesized geopolymer composites were prepared and tested. These mixes were based on metakaolin as source material and different ratios of cement kiln dust, slag, silica fume, copper, and zinc dust. Compressive strength and durability were measured for all mixes cured by different techniques. Compressive strength were measured at 3, 7, 14, 28, and 90 days while durability was tested against and exposure to sea water, nitric acid and against fire at 400 ^{o}C temperature. The results show remarkable properties for some composites with respect to strength and durability.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Date:

Signature:

Acknowledgments

First and above of all, I have to thank **Allah** for this great chance I have right now. I thank god for providing me with the opportunity to meet such helpful and wonderful people those who helped me from the start of this thesis. All praises to Allah for giving me knowledge, strength, support and patience to present this work.

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Abstract

There is a new method chosen by scientists and researchers to reduce the environmental pollution and the negative impact of the cement industry towards the atmosphere and to create environmentally friendly materials that can be used in the construction process.

There are a lot of studies and researches were done to produce a geopolymer concrete with different by-product materials which have high compressive strength with excellent properties and durability behavior. Many source materials were investigated to produce geopolymer concrete such as fly ash, metakaolin, slag and silica fume. Using geopolymer concrete since it saves the environment from many harmful materials and transferring it from a burden to economically added value. Great effort was made and performed to reduce the side effect of CKD on human and environment through utilizing CKD in different applications like bricks industry, road construction, reuse of CKD with cement clinker, cement replacement, and other miscellaneous usages. In this research, 19 mixes synthesized from metakaolin, cement kiln dust, slag, silica fume, and zinc dust were prepared and tested to evaluate their mechanical properties and durability. Three different curing regimes were applied. The compressive strength were measured after 3, 7, 14, 28, and 90 days. The durability against sea water, fire, and nitric acid were investigated. Important conclusions were drawn concerning the relationships between chemical compositions and mechanical properties.

Key Words:

Cement Kiln Dust; Slag; Metakaolin; Geopolymer Concrete; Compressive strength.

CHAPTER 1: INTRODUCTION

1.1. General

Since cement industry consumes a huge amount of energy and produce a high rate of carbon dioxide, it is considered as one of the major industries cause a negative impact on environment and human health. Therefore, geopolymer concrete considered a very powerful and promising solution for such problem because it can replace a considerable amount of conventional concrete which means that reducing the need to cement as building material. Many source materials were investigated to produce geopolymer concrete such as fly ash, metakaolin, slag and silica fume. Using geopolymer concrete since it saves the environment from many harmful materials and transferring it from a burden to economically added value. Many by-product materials are not yet investigated to be used as source materials for geopolymer concrete such as fly ash and copper dust. On the other hand, cement kiln dust considered very harmful by-product materials for both environment and human health.

The thesis is a trial to investigate the possibility of utilizing many new by-product materials such as fly ash and copper dust in geopolymer composite blends containing cement kiln dust.

1.2. Research Objectives

This research investigates the possibility of utilizing some new industrial by-products such as fly ash and copper dust in a geopolymer composite blends containing silica fume, metakaolin, slag and cement kiln dust. Also, the research aims to the following:

- Investigating the compressive strength of such used blends.
- Investigate the effect of curing regimes on the compressive strength of the tested blends.
- Investigate the durability of the tested blends through studying the effect of exposure to sea water, nitric acid and elevated temperature on the tested blends.

1.3. Thesis Layout

The proposed thesis is designed in order to help the reader to easily trace the previously mentioned objectives and scope as follows:

1.3.1. Chapter 1: Introduction

In the first chapter, an introduction and the problem definition are presented. The main objectives, the scope of work and thesis layout are also presented

1.3.2. Chapter 2: Literature Review

In this chapter; literature review about the utilization of CKD in different fields as well as a brief review about the geopolymer characteristics are reported. Also, different by-product materials and geopolymer composites are reported and presented.

1.3.3. Chapter 3: Experimental Program

In third chapter; the experimental program, starting from the characterization of the materials used, the tests carried out, the equipment's used, the mixes details are presented and discussed. Details of the above mentioned proposed tests are presented in this chapter.

1.3.4. Chapter 4: Results & Discussion

The fourth chapter represents the results of the conducted experimental program, in addition to the full discussion and the interpretation of the results. Also a brief description of the proposed technology to produce geopolymer composite blends with different by-product materials could be found in this chapter. On the other hand, details of mixes used to produce geopolymer composite blends and the results of their compressive strength could be found in this chapter.

1.3.5. Chapter 5: Conclusions and Recommendations

In the last chapter, the major conclusions and recommendations of the experimental program are introduced. The outcome of the thesis is to produce geopolymer composite blends with different percentages of by-products materials.

Chapter 2: Literature review

2.1. Introduction

Concrete is one of the most widely used materials in the construction process worldwide. It has a wide range of structural applications such as columns, beams, floor slabs, dams, pipes, pavements, and tank. Concrete has perfect properties such as high strength, high durability, high workability, and low cost. Every year, 10 billion tons of concrete is consumed all over the world.

Cement is a major factor in the concrete production. The cement industry consumes a large amount of energy with a high rate of carbon dioxide (CO_2) emissions. Cement production is the third source of CO_2 emissions in the world after power generation and transportation. it emits about 4-5 % from the total CO_2 emissions worldwide. During cement production carbon dioxide (CO_2) emits at two phases; the first phase of burning a large amount of primarily coal and fossil fuel to generate the heat used in cement production process. The second phase from the thermal decomposition of calcium carbonate during cement clinker production:

$CaCO_3$ (limestone) + heat = CaO (lime) + CO_2

Figure2.1: Factories emit CO2

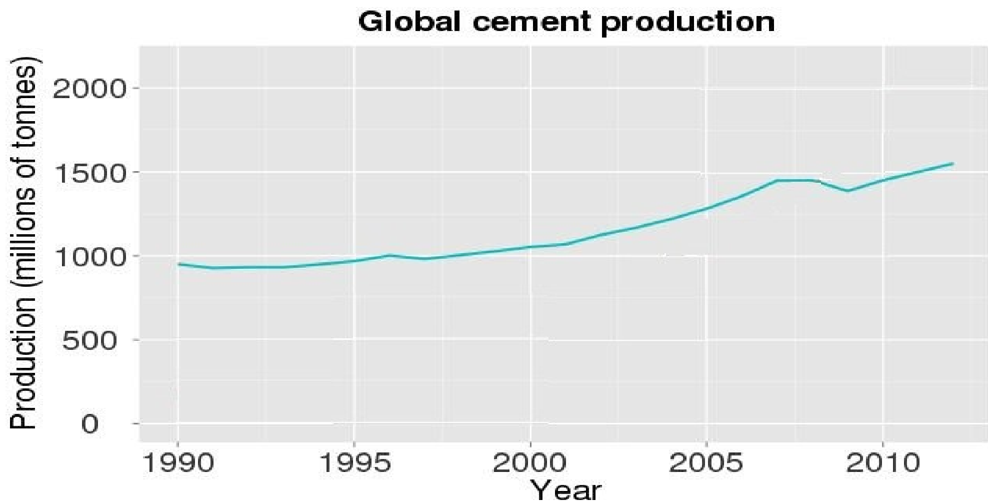

Figure2.2: Cement production per year

2.1.1. Geopolymer

There is a new method chosen by scientists and researchers to reduce the environmental pollution and the negative impact of the cement industry towards the atmosphere and to create environmentally friendly materials that can be used in the construction process. The main idea of this method is the partial or full replacement for ordinary Portland cement (OPC) with pozzolanic materials (silica fume, metakaolin, fly ash) which is activated by alkaline solutions.

The increasing worldwide production of cement to meet the future development in the infrastructure industry indicates that the concrete is the most important ingredient in the modern construction materials. It is well evident that production of Ordinary Portland Cement (OPC) not only consumes larger quantity of natural resources but also emits larger quantity of carbon dioxide gas to the atmosphere. An effort has been taken to reduce the emission of carbon dioxide gas and also to produce an environment friendly material in the development of inorganic alumino silicate polymer called geopolymer, which is obtained from materials of geological origin or a pozzolanic materials such as fly ash, Silica fume, metakaolin, and Ground Granulated Blast furnace Slag (GGBS) along with alkaline liquid. Geopolymer concrete (GPC) is a new innovative eco-friendly material which can be produced by partial or full replacement of cement in concrete.

Geopolymer cement is new type of cement that uses various chemistry and materials found in ordinary Portland cement (OPC). The geopolymer is performed by activating alumino silicate materials like slag, fly ash, and metakaolin with alkaline solutions like sodium hydroxide and sodium silicate. The activating alkaline solutions (sodium hydroxide, sodium silicate, and potassium) are formed an aqueous solutions and solve a large amounts of aluminum and silicon which is necessary for formation of geopolymer. geopolymer can work without need of OPC. geopolymers have been used in concrete as binder for 70 years and recently it have been developed due to lower effects of CO2 than OPC cement.

When geopolymer binder is formed by mixing the alumino-silicate materials with alkaline solutions, chemical reactions occurred. As a result of these reactions the binder is dissolved and the alumino-silicate gel is formed, which is then it hardens to create the geopolymer cement phase. Geopolymer cement can replace ordinary Portland cement and gives high performance in concrete. [13]

The pozzolanic materials are used in Portland cement concrete as an additional cement supplement. Cements blended with pozzolanic materials have a low early strength but it shows late strength development better than non-blended ordinary Portland cement, because the reactions of pozzolanic materials in cement system is slower than the cement reaction itself. To overcome this point, the geopolymers use an alkaline solution. this helps a solution of activating alkaline instead of mixing water. This helps for accelerating the dissolution and subsequent interaction of fly ash and slag particles.

The activating solutions (sodium hydroxide, sodium silicate, and potassium) are formed an aqueous solutions and solve a large amounts of aluminum and silicon which is necessary for formation of geopolymer . Geopolymers concrete can be created from many raw materials such as slag, silica fume, kaolin, metakaolin, and fly ash. geopolymers show an excellent fire resistance as they have a thermal insulation properties and a light weight material. [14]

Geopolymer can be created from various sources of alumino silicate. geopolymer is a new phase of concrete and considered as a new phenomenon globally. After World War II, many research and developments in geopolymer technology took place in Ukraine, France, Germany, and other countries led to the construction of many structures such as pavements, roads, railway sleepers, civil water works, fire resistance coatings, and precast elements. These structures have been over 70 years old and have excellent durability and behavior. [13]

The structure of geopolymer is composed of alumino-silicate alkali gel. This gel composition contains tetrahedral of Al and Si atoms associated with negative charges of tetrahedral of AlO4 and sodium ions. The figure below shows the structure of the geopolymer gel. [13]

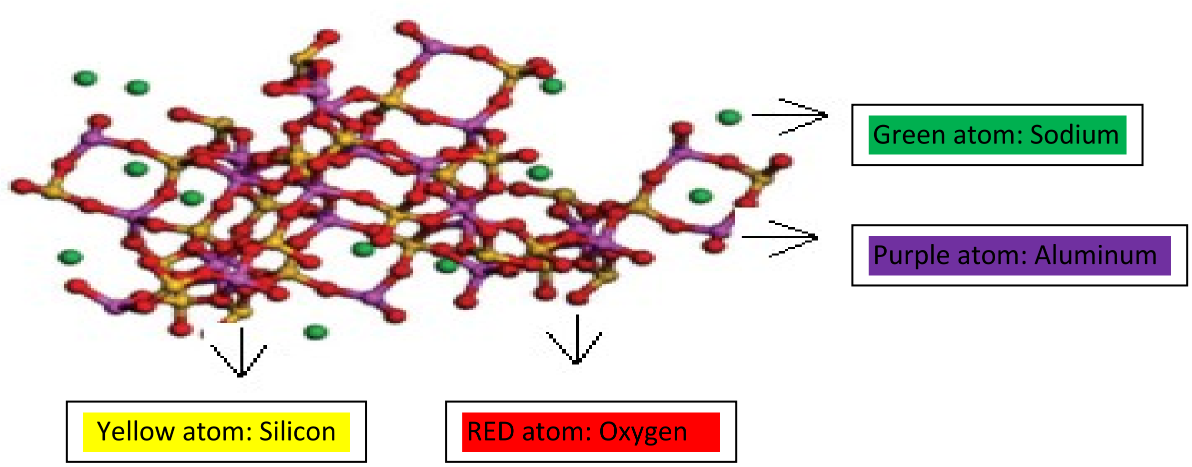

Figure2.3: Geopolymer gel phase [14]