EXPERIMENTAL STUDY OF THE EFFECT OF GRANITE CUTTING WASTE AS PARTIAL REPLACEMENT OF CEMENT

NUR ILMADIENA BINTI ANOR

UNIVERSITI SAINS MALAYSIA

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SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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EXPERIMENTAL STUDY OF EFFECT OF GRANITE CUTTING WASTE AS PARTIAL REPLACEMENT OF CEMENT

By

NUR ILMADIENA BINTI ANOR

Supervisor: TS. DR. KU ESYRA HANI KU ISHAK

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled 'Experimental Study of The Effect of Granite Cutting Waste as Partial Replacement of Cement'. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or University.

Name of Student: Nur Ilmadiena Binti Anor Signature:

Date:

Witnessed by

Supervisor: Dr. Ku Esyra Hani Binti Ku Ishak Signature:

Date:

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LIST OF SYMBOLS

g	Grams
kg	kilograms
μm	Micrometer
nm	Nanometer
°C	Degree Celsius
%	Percentage
Gt	Gigatonnes

LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
OPC	Ordinary Portland Cement
$CaCO_3$	Calcium Carbonate
OPC	Ordinary Portland Cement
GC	Green Cement
SDG	Sustainable Development Goals
RHC	Rapid Hardening Cement
QSC	Quick-Setting Cement
LHC	Low-Heat Cement
SRC	Sulphate-Resisting Cement
BSFC	Blast Furnace Slag Cement
HAC	High-Alumina Cement
WC	White Cement
CC	Coloured Cement
PZC	Pozzolanic Cement
AEC	Air-Entraining Cement
HPC	Hydrophobic Cement
MSEN 197-1	Malaysian Standard for Cement
ASTM C150	American Standard Specification for Portland Cement
SCM	Supplementary Cementitious Material
XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
SEM	Scanning Electron Microscopy
PSA	Particle Size Analysis
PME	Pengimbasan Mikroskop Elektron
PSX	Pembelauan Sinar-X

KAJIAN EKSPERIMEN KESAN SISA PEMOTONGAN GRANIT SEBAGAI SEBAHAGIAN BAHAN GANTI SIMEN

ABSTRAK

Peningkatan dalam kemajuan ekonomi dan perindustrian menyebabkan kenaikan dalam pengeluaran bahan buangan. Kajian menunjukkan 20 – 30% daripada pengeluaran global batu granit dikumpul di tapak pelupusan sampah dan boleh dilupuskan dengan menggunakan dalam penghasilan simen. Tambahan pula, simen biasa terkenal kerana memerlukan suhu pembakaran yang tinggi (1450°C) menyebabkan pelepasan karbon dioksida yang besar. Oleh itu, tujuan kerja ini adalah untuk menentukan kesesuaiannya sisa granit sebagai bahan di dalam simen dengan menganalisa ciri-cirinya serta mewujudkan keadaan yang ideal untuk sintesis simen yang mesra alam. Bahagian pertama eksperimen ini telah mengcirikan simen mesra alam menggunakan Pengimbasan Mikroskop Elektron (PME), Pembelauan Sinar-X (PSX) dan Pendarfluor Sinar-X. Bahagian kedua eksperimen ini adalah menghasilkan simen mesra alam yang telah dibancuh mengikut komposisi mineralogi tertentu. Simen biasa dan simen mesra alam ini akan dibakar pada empat suhu yang berbeza iaitu 1000°C, 1100°C, 1200°C and 1300°C. Sampel telah dihantar untuk analisa PME, PSX dan pendaflour sinar-X. Keputusan menunjukkan sisa buangan granit sesuai dijadikan bahan gantian simen kerana mempunyai sebanyak 91% bahan pozzolan semulajadi. Tambahan pula, analisa menunjukkan bahawa suhu terbaik pembakaran simen semula jadi adalah 1100°C jika dibandingkan simen biasa pada suhu 1200°C. Melalui PSX, simen mesra alam pada suhu 1100°C menunjukkan bahan aktif hidraulik seperti larnite dan brownmillerit yang dominan. Pengetahuan yang dikumpul daripada kerja ini akan dimanfaatkan untuk kemajuan industri bagi mencapai Matlamat pembangunan Mampan 2030.

EXPERIMENTAL STUDY OF THE EFFECT OF GRANITE CUTTING WASTE AS PARTIAL REPLACEMENT OF CEMENT

ABSTRACT

Increasing social demands increases waste production. Research claim that 20-30% of global granite production is a waste currently stacked in landfills and can be used in cement making. Furthermore, Ordinary Portland Cement (OPC) is infamous for requiring high sintering temperatures (1450°C), resulting in high energy consumption and carbon dioxide (CO_2) emissions. The purpose of this work is to analyse Granite Cutting Waste (GCW) as cement partial replacement and to establish ideal conditions for the synthesis of an eco-friendly cement. Firstly, GCW was characterised using Scanning Electron Microscopy (SEM), .Particle Size Analysis (PSA), X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD). The OPC and eco-friendly cement (GC) is then prepared to a specified mineralogical composition and sintered at different temperatures of 1000°C, 1100°C, 1200°C and 1300°C. The final sample were analysed. Results show that GCW are suitable in cement because it has an elongated and irregular shape and existence of microcline and anorthite crystal phases that shows GCW pozzolanicity. As a result, this demonstrates that granite cutting wastes can be employed as raw materials in the production of environmentally friendly cements. Moreover, the best sintering temperature for eco-friendly cement was discovered to be 1100 °C because hydraulic active compounds like larnite and brownmillerite were dominant in the products while OPC optimum temperature were at 1300 °C. The knowledge gathered from this work will be hugely beneficial for industrial progress in the years leading up to the 2030 Sustainable Development Goals (SDG).

CHAPTER 1

INTRODUCTION

1.1 Background to Cement Production

As the population grows, so does the need for creating infrastructure. There are three main ingredients in concrete: cement, fine aggregate, and coarse aggregate. Concrete is the most frequently used man-made construction material in the world. In most concrete, river sand is used as a fine aggregate. However, due to the widespread usage of concrete, natural river sand consumption around the world is at an all-time high (Singh et al., 2015).

Concrete is the essential building material in use across the world. In its new stage, new concrete is typically composed of roughly 12% cement and 80% aggregate (Neville, 1995). Carbon dioxide (CO_2) emissions are a significant contributor to air pollution caused by the principal component of concrete, cement. Concrete manufacturing is thought to be responsible for more than 5% of worldwide yearly carbon dioxide emissions. This is due to the calcination of the raw material used in the manufacturing of cement clinker and the burning fuel needed to maintain the high temperatures in a kiln (Ghorbani et al., 2019).

In general, "cement" may be described as any substance with the ability to bind various substances through a variety of chemical interactions (Bahhou et al., 2021; Paul et al., 2018). The presence of water frequently aids in the processes that take place. Cement is a powdered material formed mostly of calcined lime and clays, as explained in a conference paper published in the Proceeding of the 28th International Symposium, 2017 in Sri Lanka. The clay contains silica, alumina, and iron oxide, whereas the calcined lime contains calcium oxide (Dunuweera et al., 2018)

The most prominent kind of cement, Ordinary Portland Cement (OPC), is used in all normal concrete buildings. Each year, around 3,8 million cubic metres of cement are produced for worldwide use, making it the most frequently used cement in the world. It is a reasonable choice to use this cement in any concrete project (Imbabi et al., 2012).

The chemical constituents of an Ordinary Portland cement (OPC) are shown in **Table 1.1** (Ali et al., 2008).

Table 1.1 Chemical constitutions of Ordinary Portland Cement (OPC) (Ali et al., 2008)

COMPONENT	AMOUNT (%)
Lime (CaO)	60.0 - 67.0
Silica (SiO_2)	17.0 - 25.0
Alumina (Al_2O_3)	3.0 - 8.0
Iron Oxide (Fe_2O_3)	0.5 - 6.0
Magnesia (MgO)	0.1 - 4.0
Sulphur Trioxide (SO_3)	1.0 - 3.0
Soda and/or Potash (Na_2O + K_2O)	0.5 - 1.3

The extraction and processing of OPC are the first steps in the production process. In the case of hard rocks such as limestones, slates, and some shales, the raw materials used in cement-making are recovered through quarrying, with the assistance of blasting where necessary. The manufacturing process of OPC consists of four stages: (1) crushing and grinding the raw materials, (2) mixing materials in the proper proportions, (3) burning the prepared mix in a kiln, and (4) grinding the burned product, referred to as "clinker," along with about 5% gypsum (to control the time required for the cement to set) (Sutar et al., 2021).

Cement is burned in a kiln that is progressively rotated at an angle of a few degrees to the horizontal. The raw material feed is gradually lowered into the kiln until it reaches the lower, or firing, end. The fuel used in the combustion process may be pulverized coal, oil, or natural gas injected via a pipe. The firing end temperature varies between approximately 1,350 and 1,550 °C, depending on the burned raw materials. A heat exchanger is frequently used at the kiln's back end to improve heat transfer to the incoming raw materials. The kiln produces small modules of clinker as a result of the burning process. The clinker and the required gypsum are ground to a fine powder in horizontal mills similar to those used for grinding the raw materials (Sutar et al., 2021).

Anthropogenic emissions of carbon dioxide to the atmosphere come from three primary sources: (i) oxidation of fossil fuels, (ii) deforestation and other land-use changes, and (iii) carbonate decomposition: cement, the largest source of emissions from the decomposition of carbonates.

Cement has been used since ancient times. But it was following World War II, the production of cement accelerated rapidly worldwide, with current levels of global production equivalent to more than half a tonne per person per year. **Figure 1.1** shows that global cement production has increased more than 30-fold since 1950 and almost 4-fold since 1990, with much more rapid growth than global fossil energy production in the last two decades. Since 1990 this growth is mainly because of rapid development in China, where cement production has grown by a factor of more than 11, such that 74 % of the global increase in cement production since 1990 occurred in China (Andrew, 2019).

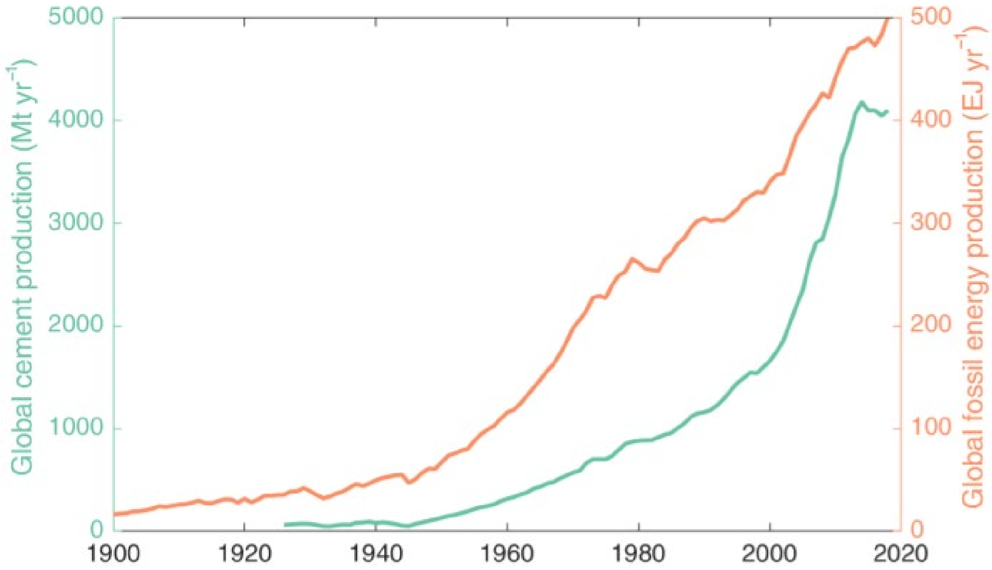

Figure 1.1 Global Cement and fossil energy production to 2018 (Andrew, 2019; BP, 2019; Mohr et al., 2015; USGS, 2018)

In 2005, the global cement production was approximately 2.31 Gt after decades of unrelenting growth. Cement production increased by about 300 % to 1970s production levels and by twofold compared to 1990 production levels (Zhu, 2011). Cement industry distribute 25 billion tonnes of cement annually everywhere in the globe and produce 2.28 billion ton/year internationally (Lai, 2015). Cement manufacture is an energy-intensive process, with energy accounting for 20-40 % manufacturing costs on average. The Portland cement variety, which contains 95 % cement clinker, is the most common today. Furthermore, cement manufacturing represents the most remarkable potential CO_2 emission savings, accounting for roughly one-fourth of expected total CO_2 emissions in sector (Bakhtyar et al., 2017).

For this reason, this work aims to characterize granite cutting waste as a substitution in cement, to assess the ability of granite as a partial replacement in portland cement by evaluating its properties through characterization process, and lastly to establish optimal conditions of the synthesis of the eco-friendly cement using granite cutting waste.

1.2 Overview of Cement Production in Malaysia

Peninsular Malaysia and East Malaysia occupy the northern portion of the island of Borneo, respectively. Peninsular Malaysia consists of thirteen states that contribute for 85% of the country's gross domestic product. These states managed by a single cement market distinct from the Sabah and Sarawak cement markets in East Malaysia.

Malaysia's cement consumption per capita of around 600kg exceeds that of established nations like the United States and Australia, as well as neighboring Southeast Asian cement powerhouse like Vietnam and Thailand. As is the case in the majority of emerging nations, the market sources for the Malaysian cement industry may be associated to urbanisation and infrastructural growth. Since the late 1980s, the country's demand for cement has increased due to government attempts to rebuild infrastructural in remote regions and establish free trade zones. Cement consumption increased at a six percent compound annual growth rate (CAGR) from 2010 to 2015.

The expert economic and analyst from CEIC reported on the Malaysia's cement production rates and was reported the cement production at 1,571.000 Ton th in Oct 2018 as illustrated in **Figure 1.2**. This records an increase from the previous number of 1,483.000 Ton th for Sep 2018. This production data is updated monthly, averaging 1,730.000 Ton th from January 2013 to October 2018. The data reached an all-time high of 2,496.000 Ton th in Jan 2017 and a record low of 1,299.000 Ton th in Feb 2018.

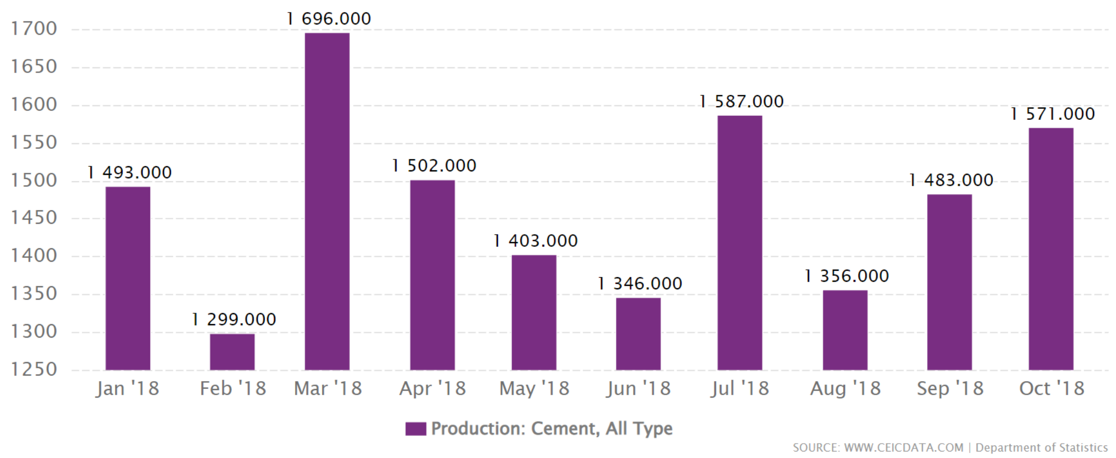

Figure 1.2 Malaysia's cement production from Jan to Oct 2018 (CEIC, 2019)

Malaysia mostly relies on non-renewable energy such as fossil fuel and coal to generate the production activities yet if the economy is too dependent on this energy, it will cause an expansion in CO_2 emission that consequently responsible for the global warming (Chik et al., 2014). Furthermore, Malaysian Government's aspiration is to achieve a 40% voluntary reduction of CO_2 emission by 2020 in the Low Carbon Society Blueprint project toward transforming Malaysia into a Low Carbon Nation (Bakhtyar et al., 2017).

1.3 Cement Production Environmental Impact

Cement is one of the most energy intensive building materials, and its production releases a significant amount of carbon dioxide during the synthesis of OPC. The cement industry is the third largest emitter of carbon dioxide after the accommodation sectors, not because cement is a particularly damaging material but because it is so widely used and popular. In a similar manner, McCaffrey proposed that the cement industry's carbon dioxide (CO_2) emissions can be lowered by reducing the amount of calcined material in cement, the amount of cement in concrete, and the number of facilities that are using cement (Vairagade et al., 2017)

There are two aspects of cement production that result in emissions of CO_2. First is the chemical reaction involved in the production of clinker, as carbonates (largely CaCO3, found in limestone) are decomposed into oxides (largely lime, CaO) and CO_2 by the addition of heat (Andrew, 2019). The second source of emissions is from the combustion of fossil fuels to generate the significant energy required to heat the raw ingredients to well over 1000 ◦C, including energy from purchased electricity, which could add a further 60 % to the process emissions (IEA, 2016). Therefore, total emissions from the cement industry could contribute as much as 8 % of global CO_2 emissions. This process and energy emissions are most often reported separately in global emissions inventories (Andrew, 2019; le Quéré et al., 2018).

Malaysia has joined other emerging and industrialised nations in committing to innovations that could drastically lower overall emissions by changing cement composition. For example, as the cement standard writing organization, the Cement and Concrete Association of Malaysia has effectively demanded the development and revision of the new Euro standard for cement (Bakhtyar et al., 2017; Yuzuru & Siong, 2013).

Also, according to Cement Sustainability Initiative (CSI) and the European Cement Research Academy (ECRA), the average rate of substitution of concrete components with waste and by-products in Europe is greater than 60 % for an industry sector and as high as 95 % on an annual basis (Sandanayake et al., 2020).

The Malaysian building sector reached a crucial point regarding waste composition and volume. Problems in the removal of such waste are mounting. Large-scale construction and infrastructure development projects have increased construction waste generation for many years and harm the ecosystem (Begum et al., 2007).

Granite cutting waste (GCW), a solid industrial waste, is created by removing and cutting/polishing granite stone into required shapes (Ghannam et al., 2016; Lokeshwari and Jagadish, 2016). By-products of granite manufacturing account for 20–30% of global output (Soltan et al., 2016; Tchadjié et al., 2016), with millions of tonnes currently held in landfills (Baltakys et al., 2021). One option to recycle this waste is to use it in the construction sector, particularly in the cement manufacturing process. As a result of these concerns, the new generation of environmentally friendly cementitious materials has been awaited with great expectations in recent decades (Sivakrishna et al., 2020) .

1.4 Problem Statement

Prior to usage, granite is often chopped and polished after quarrying. The processes of cutting and polishing generate a substantial amount of cutting waste. Granite cutting waste (GCW) has become a severe issue throughout the mining zones (Allam et al., 2014).

The majority of granite quarrying waste consists of: a) undersized masses that are impractical for sawing with gang saws; b) blocks with structural faults that render them unsuitable for sawing; and c) Small fragments and bits of granite. It is difficult to remove these wastes from quarrying locations since their removal is not cost-effective and they are only removed off quarry roads to help improve transportation and or accumulated at any landfill (Allam et al., 2014). Jigani Industrial area in India has about more than 300 granite industries and producing more than 150 tonnes of granite waste every day. According to the literature, total of 20 – 30% of granite global production ends up being a by-product, of which, millions of tons are currently stored in landfill sites (Baltakys et al., 2021).

Malaysia is a nation that engages in many industrial activities, including manufacturing, building, agriculture, mining, and quarrying, thus, hazardous wastes are inevitable. Malaysia defines hazardous trash as scheduled waste (Artika H et al., 2019). The production of scheduled wastes rose by 8.3% yearly between 2015 and 2019, reaching 4 013.2 tonnes in 2019. Power plant activities recently documented 24.2 % of the scheduled wastes created at the national level in 2019, followed by metal refinery (12.2 %), chemical industry (10.7 %), and electric & electronic manufacturing (10.1 %) (DOS, 2021). Consumption and disposal rates are rising faster than Malaysia's utilities can cope because of population growth. As a consequence, the majority of it ends up in landfills. In Malaysia, the overwhelming majority of landfills are open-air pits which is inexpensive, but very damaging to the environment. Surface and groundwater pollution is one of the challenges inherent to open-land landfills. All items in a landfill are effectively lost to society and a waste of natural resources (Clean Malaysia, 2015). Thus, putting the waste for a good use are needed than stacking in landfill.

There are two major contributors to these emissions. Since the 1930s, the energy demand for cement manufacturing has generated 0.5 to 5% of yearly worldwide CO_2 emissions, and its proportional contribution to annual CO_2 emissions has increased with time. However, the 'process-based' CO_2 emissions linked with the calcination of $CaCO_3$ to CaO in a cement kiln currently account for a greater proportion of the cement kiln's CO_2 emissions than those linked with its energy needs. (Miller and Myers, 2020). Consequently, operating the cement production under suboptimal conditions will result in increased energy consumption and net CO_2 emissions. It is necessary to establish the ideal conditions for producing eco-friendly cement from granite in order to reduce energy consumption (CO_2 emissions) while retaining cement characteristics.

The use of GCW as an addition to or a substitute for OPC cement or sand has been studied in a sizable number of articles. The scientific literature states that adding some GCW to cement improves the properties of the concrete mix as well as the physical and mechanical characteristics of hardened concrete (Ghorbani et al., 2018, 2019b; Ramos et al., 2013). The majority of these articles, however, concentrated on partially replacing OPC; there is currently a scarcity of information about the use of GCW as a raw material in the manufacture of environmentally friendly cements. Thus, the purpose of this study is to characterise the granite cutting waste and develop the ideal conditions for the synthesis of an eco-friendly cement by partly replacing with an industrial by-product of granite cutting waste.

1.5 Objectives of Research

1. To characterize the granite cutting waste sample and to assess the ability of granite as partial replacement in Portland cement by evaluating the cement properties.

2. To establish the optimal conditions of the synthesis of the eco-friendly cement using granite.

1.6 Thesis Outline

The goal of this study was to investigate the current status and factor that contribute to industrial waste as supplementary substitution element in the cement production. In addition, this study focused on the Malaysia construction industry mainly the cement, and concrete manufacturer. Literature review was utilized to provide guidance for the direction of this study and as basis for the research and experiment work. A local granite waste was obtained from a granite quarry in Northern Kedah. The samples are then characterized and tested using analytical technique analysis to shows it effectiveness as a supplementary in cement making. The data gather will help to achieve the goal. The findings of this study will help improve the implementation of industrial waste as supplementary cement replacement in construction industry.

CHAPTER 2

LITERATURE REVIEW

2.1 Cement Manufacturing Process

Cement is a solid composite material consisting of clinker, gypsum, and numerous additives. Concrete, meanwhile, is a mixture of cement, water, fine sand, and coarse aggregates that is commonly used in civil engineering buildings. Moreover, cement has a strong hydraulic binding capacity, so after a few days of reaction with water, it forms a hard and durable substance (Frederick M. Lea, 2016).

2.1.1 Cement Raw Material

Cement compositions are very important as from the ingredient functionality and amount of ingredient the desired qualities of cement are achievable. Portland cement is a fine grey or white powder made up primarily of calcium silicates, aluminates, and aluminoferrites. It has been stated that around 30 distinct raw materials are utilised in the production of cement, which can be categorised into four types: calcareous, siliceous, argillaceous, and ferriferous (Shular and Neulicht, 1994). There are 8 major ingredients of cement as shown in **Table 2.1**.

Table 2.1 Percentage of a Cement composition (Civil Today, n.d.)

Ingredient	Percentage In Cement
Lime	60-65
Silica	17-25
Alumina	3-8
Magnesia	1-3
Iron Oxide	0.5-0.6
Calcium Sulfate	0.1-0.5
Sulfur Trioxide	1-3
Alkaline	0-1

Cement is a mixture of Calcium oxide(CaO) (62.66%), Silicon oxide(SiO2) (19-22%), Aluminum tri-oxide (Al_2O_3) (4-8%), Ferric oxide (Fe_2O_3) (2-5%), Magnesium oxide(MgO) (1-2%) and also Selenium, Thallium and other impurities (Singh Gaharwar et al., 2016).

Iron oxide (Fe_2O_3, Fe_3O_4), quartz (SiO_2), and clay/bauxite make up the remainder. Cement production requires a calcium source, such as $CaCO_3$ or CaMg $(CO_3)_2$, which accounts for 80–90% of the total (Al-silicates) **(**(Abdul-Wahab et al., 2021; Aïtcin, 2016).

In addition to chemical composition, the textural and microstructural characteristics of carbonate rocks influence the dissociation of $CaCO_3$ in carbonate rocks. Fine-grained calcite ($CaCO_3$) dissociates at lower temperatures than holocrystalline calcite ($CaCO_3$) (Abdul-Wahab et al., 2021b) In addition, calcium silicates and aluminates can only form in the presence of lime in adequate quantities. Lime deficiency diminishes the cement's strength and accelerates its setting. In addition, the presence of an excessive amount of lime causes cement to expand and crumble (Civiltoday, 2017).

In addition, at elevated temperatures, the aforementioned oxides undergo chemical reactions, resulting in the formation of more complex molecules (Elimbi et al., 2011). For instance, the reaction between $CaCO_3$, $Al_3(SiO_3)_2$, and Fe_2O_3 would produce a complex combination of alite, $(CaO)_3SiO_2$; belite, (CaO)2SiO2; tricalcium aluminate, Ca3(Al2O3); and ferrite phase tetracalcium aluminoferrites, $Ca_4AlO_2Fe_2O_3$, along with the evolution of CO_2 gas in clinker of OPC (Dunuweera and Rajapakse, 2018).

Cement should include enough silica to create dicalcium and tricalcium silicate. Cement gains strength from silica. Cement typically contains roughly 30% silica by volume. The reactivity of the cement raw mix is significantly influenced by the silica's mineralogical makeup and features of its dispersion. A minor increase in the silica content of the raw mix, according to experiments, may significantly lessen phase development in the clinker. Compared to free or uncombine silica, such as quartz, silicates react more quickly (Abdul-Wahab et al., 2021).

The hydrous aluminosilicate clay minerals used in cement production are essentially a source of both silica and alumina (Hewlett 2003; Ludwig and Zhang 2015). Aluminum oxide, or alumina (Al_2O_3), gives cement its quick-setting properties. The necessary alumina amount needed to be present, which reduces the clinkering temperature. Furthermore, too much alumina weakens the cement (Civiltoday, 2017).

However, the sequence of change in all clays is the same: dehydration, followed by dihydroxylation, then the disintegration of crystal structures. Al_2O_3 and SiO_2 are reactively released from the clay as a result of this reaction. Cement manufacture then takes use of the existence of this reactive state (Abdul-Wahab et al., 2021).

Iron oxide in the ferrous state promotes raw material reactivity. Cement acquires colour from iron oxide. it acting as a flux. Tricalcium alumino-ferrite is created at extremely high temperatures when it participates in the chemical reaction with calcium and aluminium. Cement gets its hardness and strength from tricalcium alumino-ferrite (Civiltoday, 2017). Fe_3O_4 may contain more iron than FeO, however it is only reactive at 900 °C. Limonite (FeO, OH.H_2O) is frequently found in laterite, and it typically contains amorphous silica and is much more reactive than laterite (Abdul-Wahab et al., 2021).

Calcium sulphate, which is present in the form of gypsum in cement, is another essential raw element for cement production. Its role is to retard or slow down the setting of cement (Wright et al. 2016) . Alkaline and sulphur trioxide are two substances that are unnecessary for cement manufacture and should not exceed 2 %. This is because excessive amounts of sulphur trioxide and alkaline materials can lead to faulty cement and efflorescence. The white powder that forms on the surface of unsealed concrete is known as efflorescence. When moisture moves through the slab, it carries soluble salts to the surface, generating efflorescence (Doug Bannister, 2020). The majority of efflorescence is thought to be temporary and it's completely safe. (Portland Cement Association, 2004).

Chemically speaking, the reactivity of a raw mixture depends heavily on the availability of reactive components. As a result, it is preferable that raw mixture components react at temperatures comparable to the carbonate decomposition temperature. Clearly, highly reactive fine carbonates do not interact well with low-reactive clays including silica, iron, magnesium, potassium, etc (Abdul-Wahab et al., 2021).

2.1.2 The Process of Cement Production

Cement is made in six phases using acceptable basic materials as shown in **Figure 2.1**. Mining of limestone/raw materials; grinding, homogenisation, and blending of various raw mixtures; the preheater stage; pyro treatment in the kiln; clinkerization; and grinding, packaging, and shipping of products (Abdul-Wahab et al. 2021) The raw materials used to make cement may be divided into four basic components: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous).

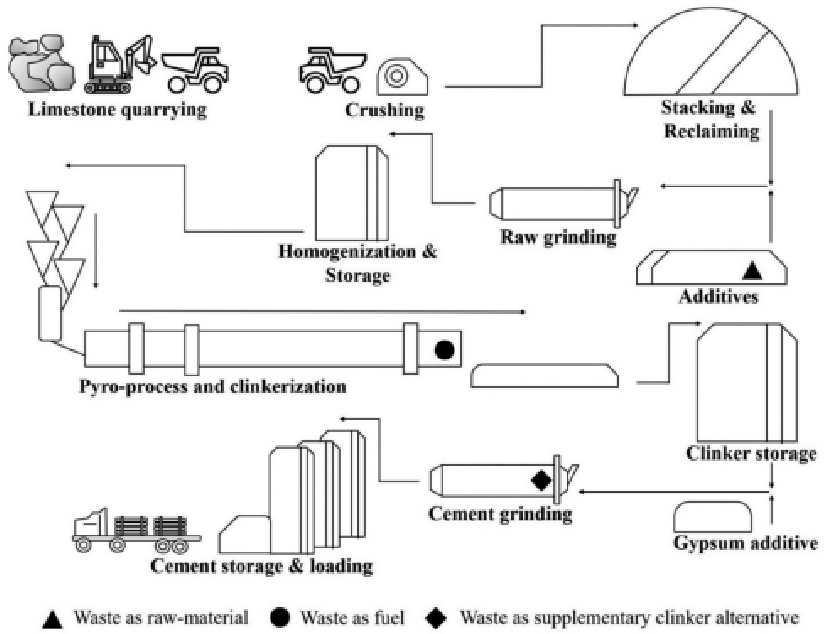

Figure 2.1 Cement Processing with waste utilization (Abdul-Wahab et al., 2021)

Limestone, laterite, bauxite, kaolinite, clay, iron ore, sandstone, and other necessary raw materials are extracted in stage one. Calcium may be found in limestone, whereas aluminium can be found in bauxite and kaolinite. The requirements for iron and, to some degree, silica are met by laterite, red ochre, and iron ore. Silica may be found in quartz-phyllite and sandstone (Hewlett, 2013). Cement kilns are often situated adjacent to abundant limestone sources since the demand for limestone much surpasses that of other components, and other raw materials are delivered to the facility (Abdul-Wahab et al. 2021). Locating cement kilns next to limestone quarries makes it simple to handle the main raw material, conserving energy and increasing the efficiency of cement manufacturing (Kääntee and Markus, 2003).

Calcium carbonate ($CaCO_3$) is manufactured from quarries that are often situated near to cement manufacturing facilities from naturally occurring calcareous deposits such as limestone, marl, or chalk. To assure chemical composition, very tiny quantities of "corrective" additions, such clay, may be needed to compensate for Fe_2O_3, Al_2O_3, and SiO_2 (Singh Gaharwar et al. 2016).

To be broken down into smaller bits, raw limestone is carried to crushers. The quality of cement depends on the chemistry of raw meal, which is closely monitored and regulated. Different raw materials are mixed in a predetermined proportion to achieve a specified chemical composition. The crushed pieces are then processed together to for the raw material (Singh Gaharwar et al. 2016). In recent years, computer-aided mining plans have been frequently used to help in the extraction of high-quality limestone. The extracted limestone is crushed in crushers for size reduction, with current machines' improved technology it will resulting in optimum crushing. As part of the mining process, stacks of diverse raw materials stored in stockpiles are also processed (Abdul-Wahab et al., 2021a; Hewlett, 2013).

The characterization of diverse raw materials occurs in stage two. The composition of the raw materials is established by this quality control procedure. The appropriate raw mix designs are then created with the assistance of different quality control tests. The desired fine powder is subsequently produced by grinding the raw materials in appropriate ball mills or vertical roller mills (VRMs), both of which are common grinding mills, and is then kept in pre-homogenization silos (Abdul-Wahab et al. 2021) One tons of cement requires around 1450 kg of dry raw ingredients. About 35 % of the weight of the raw materials is lost as CO_2 and water vapors (Singh Gaharwar et al. 2016).

The raw ingredients are blended and mashed to create a uniform blend with the necessary chemical composition after a preliminary pre-blending step. The raw material's fineness and particle size dispersion are crucial aspects of the burning process(Li et al., 2012).

After mixing, the manufacturing process continues in a rotary kiln by calcining the raw material (such as breaking down $CaCO_3$ at around 900 °C, releasing CO_2, and leaving CaO) (Singh Gaharwar et al. 2016). The fundamental chemistry of the cement manufacturing process begins with the breakdown of clay minerals into SiO_2 and Al_2O_3, on the one hand, and the decomposition of calcium carbonate ($CaCO_3$) at around 900 °C to produce calcium oxide (lime) freeing CO_2 on the other.

This is followed by the clinkering process, in which CaO combines with silica, alumina, and ferrous oxides at high temperatures (1,400°C to 1,500°C). To fulfil the desired composition, further elements may be added to the raw material combination such ah silica sand, foundry sand, iron oxide, alumina residues, blast furnace slag, and gypsum residues (Singh Gaharwar et al. 2016).

This is followed by the clinkering process, in which CaO combines with silica, alumina, and ferrous oxide at high temperatures to generate calcium silicates, aluminates, and ferrites. The temperature of the flame and the gases created is close to

2,000 °C. The hot clinker drops from the kiln into the cooler, where it must be cooled as soon as possible in order to enhance clinker quality and recover energy by secondary heating air. Grate coolers are commonly used for this purpose. The feed is passed through, coming into collision with anti-directional swirling hot kiln exhaust gases travelling in the opposite direction. The resulting clinker is crushed with gypsum and other additions to make cement (Atmaca and Yumrutaş, 2015; Singh Gaharwar et al., 2016) .

Thermal energy is collected from hot flue gases in these cyclones, and raw meal is warmed before entering the kiln, allowing the essential chemical reaction to proceed faster and more effectively (Singh Gaharwar et al. 2016). The precalciner material is then fed into the kiln. Fuel is burnt directly into the kiln to attain temperatures of up to 1450 °C. while the kiln spins at 3-5 RPM, times per minute, the material slides into hotter zone and the forceful heat account to numerous physical & chemical processes yielding clinker as result (Singh Gaharwar et al. 2016).

The cooled clinker is then crushed with gypsum and limestone to make portland cement, and with other ingredients to make composite or blended cement (Singh Gaharwar et al. 2016).

The finished product is homogenised and kept in cement silos before being transported to a packing mill to be boxed. The blending ingredients are hydraulically active compounds (e.g. natural pozzolane, fly ash, blast furnace slag, and occasionally bottom ash). Carbon residues (usually from coal-fired power stations) should not be present in fly and bottom ashes. CaCO3 is occasionally used as a filler in tiny amounts (Singh Gaharwar et al. 2016).

At that stage, there are two distinct production processes: dry and wet. The raw ingredients are ground, combined, and fed into a cement kiln, which is a horizontal rotating cylinder, for the dry process. In the wet process, water is added to the raw materials before being fed into the kiln, to create slurry. The dry process is more environmentally friendly and emits less CO_2, due to the additional use of fuel needed in the wet process (Singh Gaharwar et al. 2016).

The cement kiln as seen in **Figure 2.2**, is heated to around 1450°C and employs a range of fuels, including coal, biomass, and waste materials such as old rubber tyres. Only at these high temperatures do the raw materials' chemical and physical properties changes. These alterations result in what is called as 'Clinker,' which emerges from the kiln in little marble-sized fragments. After cooling, these clinkers are pulverised further to produce OPC (Singh Gaharwar et al. 2016).

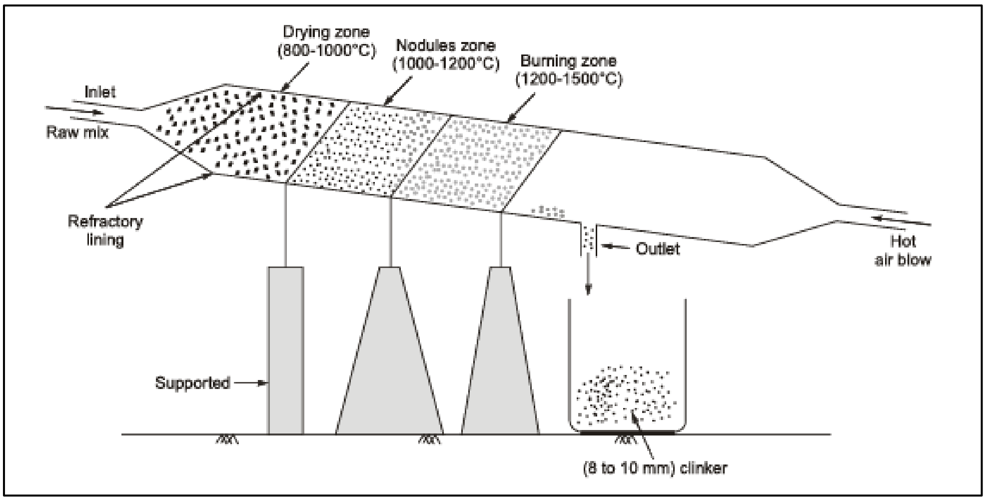

Figure 2.2 Calcination in Rotary Kiln ("Building-Materials-Mpsc, 2019)

From the **Figure 2.3** above, Zone 1 is the drying zone where the raw mix is fractioned into a smaller size. Zone 1 also where any water or moisture left will be evaporated. Zone 2 here is the nodule zone where the major breakdown of material which is calcination happen. Next is the Zone 3 where the mix is called nodules. This nodule will slope down and the major chemical reaction between ingredient of clinker occurs such as lime, silica and alumina.

In the wet process, water is added to the raw mill during the grinding of the raw materials in ball or tube mills, thereby producing a pumpable slip or slurry of approximately 65 percent solids. The slurry is agitated, blended, and stored in various kinds and sizes of cylindrical tanks or slurry basins until it is fed to the pyroprocessing system (Richard Marinshaw et, al. 1994)

2.2 Type of Cement

There are over ten distinct types of cements used in building, and they range in composition and are made for specific applications. Rapid-hardening cement (RHC), quick-setting cement (QSC), low-heat cement (LHC), sulphate-resisting cement (SRC), blast furnace slag cement (BFSC), high-alumina cement (HAC), white cement (WC), coloured cement (CC), pozzolanic cement (PZC), air-entraining cement (AEC), and hydrophobic cement (HPC) are the examples. When compared to OPC, RHC has a higher lime concentration. The goal of having a high lime concentration is to achieve great strength in the initial days. That is used in concrete to remove formwork quickly. Since cement hardening is caused by the creation of $CaCO_3$ by the absorption of atmosphere CO_2 by CaO, higher CaO leads to higher $CaCO_3$ formation even at the initial stages, leading in quick hardening (Dunuweera and Rajapakse, 2018).

It is feasible to alter the qualities of portland cement by varying the proportions of its constituent chemical compounds, given knowledge of their fundamental properties. AASHTO M 85 and ASTM C 150, Standard Specification for Portland

Cement, identify eight fundamental forms of portland cement concrete in the United States. There are several different forms of mixed and proprietary cements not included here ("Portland Cement – Pavement Interactive," n.d.).

Cement is the binding component used to create concrete. When water comes into touch with cement, a chemical process referred to as hydration begins. The reaction occurs at the surface of the cement particle, where a fibrous growth binds the individual cement grains and simultaneously bonds the aggregate. The majority of this process occurs within the first 30 days, but it will keep going as long as unreacted cement and water are present, and there is room for the hydration product to expand (Terry Harris, 2012).

2.2.1 Ordinary Portland Cement

This type of cement is well-known, as it is the most basic. In other words, it can be refer to as a control kind of cement because all other cement are derived from it, and is the ideal type for common concrete building projects such as plastering, masonry, etc. The majority of house construction projects continue to rely on this sort of cement (Saad Iqbal, 2019). It is employed in concrete construction where there is no sulphate exposure in the soil or ground water (Serina Ho, 2021).

Cement is the main component of cement paste, which serves as the binding agent in a concrete. It is a hydraulic cement that hardens into a solid mass when mixed with water. PCC is formed when it is interspersed in an aggregate matrix. Portland cement has been used as a product for almost 175 years, and its behaviour is well studied empirically. Chemically, however, portland cement is a complicated material with unknown processes and interactions (Serina Ho, 2021). The Portland Cement Association (PCA) and ASTM C 125 define Portland cement is defined as a hydraulic cement that sets and develops strength through a chemical interaction with water through the development of hydrates and is capable of doing so under water.

Because each nation has its own requirements, there is no global standard for cement. For instance, MSEN 197-1 (Malaysian Standard for Cement - Composition, specifications and conformity requirements for common cements), which was adapted from the European Standard, is the cement standard in use in Malaysia. There are 5 basic cement kinds and 27 other varieties of common cement listed in MS EN 197-1 (Serina Ho, 2021):

a) CEM I - Portland cement
b) CEM II - Portland-composite cement
c) CEM III - Blastfurnace cement
d) CEM IV - Pozzolanic cement
e) CEM V - Composite cement

Despite the fact that MSEN197-1 is the most prevalent cement standard in Malaysia, the American Standard ASTM C150 (Standard Specification for Portland Cement) is occasionally recommended for certain projects. Both MSEN 197-1 and ASTM C150 categorised cements into five primary kinds, namely Type I through Type V. However, the manner in which these two standards identify types of cement is somewhat distinct. MSEN classification is based on composition, whereas ASTM classification is based on the composition and application of the potential phase. For quick reference, **Table 2.2** provides an overview of the kinds of cement categorised in both standards.

Table 2.2 Type of cement according to MSEN 197-1 and ASTM C150 (Serina Ho, 2021)

TYPE	MSEN 197-1	ASTM C150
I	Portland Cement	Normal
II	Portland-composite Cement	Moderate Sulfate Resistance
III	Blastfurnace Cement	High Early Strength
IV	Pozzolanic Cement	Low Heat of Hydration
V	Composite Cement	High Sulfate Resistance

2.2.2 White Cement

White Portland cement is created from natural resources that include extremely minimal iron oxide and magnesium oxide (less than 0.3 % by mass of clinker) (which give the grey colour in OPC). China clay (white kaoline) is commonly used in conjunction with chalk or limestone that is free of required impurities (Basil Salah, 2018). The grey colour of cement is caused by C4AF (tetra-calcium alumino ferrite), which is introduced throughout the cement production process to lower the clinkering temperature (Saad Iqbal, 2019).

White cement is exclusively used for architectural or aesthetic purposes, such as on a building's façade. White cement is mostly blended with fine aggregate and only sometimes with a coarse aggregate (Cassar et al., 2003)

Because of the limited quantity of soluble alkali, there is no need to worry about staining as normally would with regular Portland cement (Saad Iqbal, 2019). White Portland Cement is created from resources that include extremely little iron oxide and manganese oxide. To prevent pollution, oil or gas is substituted as a kiln fuel rather than coal ash during manufacture (Saad Iqbal, 2019).