UTILIZATION OF ROTARY KILN ASH IN CONCRETE PRODUCTS

HAMK
HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Construction engineering

Autumn semester, 2021

Abdulkareem, Qasim Hussein

HAMK
HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Construction engineering | Abstract

Author Abdulkareem, Qasim Hussein | Year 2021
Subject Utilization of Rotary Kiln Ash in Concrete Products
Supervisor Ahmad Shahgordi, Annika Suormunen, Tuomas Vähä-Jaakkola

The aim of this thesis was to simulate the hypothesis of the terminus of an essential ingredient of a concrete mix, as well as answer the question of the possibility of utilizing a recycled material in terms of environmental and economic aspects. This thesis was commissioned by Fortum Waste Solution Oy and Lujabetoni Oy.

However, the constant demand for new buildings translates into an ever-growing annual extraction of natural resources requiring a massive use of energy and causing greenhouse gas emission on top of other environmental damages such as eutrophication depletion of the stratospheric ozone layer, air, and water pollution. However, utilization of Rotary kiln ash in concrete products could reduce the threat of disappearance of the landscape, which is the natural resource of aggregate, minimize the Co2 emission, and energy consumption. Economically it would decrease the cost of energy and labor required to gain conventional aggregate.

This study discusses the durability of the concrete product, which is manufactured utilizing Rotary kiln ash with aggregate in different percentages or utilizing the Rotary kiln ash alone instead of the aggregate. Six different trials mix were carried out to avoid all disputes and to provide a clear outcome. One trail mix, which had zero percent of Rotary kiln ash was accomplished to be in a comparison with the other trails. For obtaining a better view of the interaction of the product, five trials that contained 25%, 45%, 55%, 75%, and 100% of Rotary kiln ash were molded and tested for compressive strength. The water-cement ratio, type and quantity of fine aggregate and cement were fixed in trials. Compressive strength tests for trials with Rotary kiln ash were accomplished at the age of 1, 3, 7, 14, and 28 days, and for typical specimens, a compressive strength test was carried out only at the age of 14 and 28 days. The axial tensile strength test completed at the age of 28 days for four (4) concrete specimens comprised 0%, 45%, 75%, and 100% of Rotary kiln ash.

Compressive strength results showed a gradual increase in the strength of the products. Two different concrete grades were achieved as a result of trials according to the six various concrete compressive strengths obtained at the age of 28 days. This thesis provides some suggestions for future research as well as it can be a guideline for any concrete mix that utilizes Rotary kiln ash.

Keywords Concrete mix, Rotary kiln ash, typical specimens, Rotary kiln ash specimens, compressive strength, flexural strength

List of Abbreviation

BS	British Standard
ACI	American Concrete Institute
DOC	Dissolved organic carbon
TDS	Total dissolved solids
pH	Power of hydrogen
As	Arsenic
Ba	Barium
Cd	Cadmium
Cr	Chromium
Cu	Copper
Pb	Lead
Ni	Nickel
Sb	Antimony
Se	Selenium
Zn	Zinc
Hg	Mercury
SO4	Sulfate
Cl	Chlorine
F−	Fluoride

Contents

Appendices

1 Introduction

The primary aim of this thesis was to provide information about the potential of utilizing the Rotary kiln ash in concrete products by replacing it with aggregates in various percentages and then testing the specimens with a typical concrete product test. For the recycled material to be reliable, testing is vital and there are many different methods to test the concrete specimens. The specific tests that were being conducted in this thesis are the flexural test, which is a test for axial tensile strength of concrete, and the compression test which is the test that assesses the compressive strength of the concrete. Typical concrete is a mixture of three main components: water, cement, and aggregates. The durability of concrete and cement composites indicates that the cement hardens and acquires strength through a chemical reaction called hydration (Diamond, 2007). The characteristics of the concrete are usually dominated by the quality of the cement paste. Hardened concrete is achieved by the hydration of cement and water and complete hardening lasts twenty-eight days after casting. The 20-30 MPa is the final anticipated product's compressive strength when the compressive strength refers to the resistance of concrete against a compressive force (Nevada Ready Mix, n.d). Similarly, the concrete product should withstand the compressive strength of 20-30 MPa per square millimeter on the 28th day after casting. In addition, a flexural test on the final product was conducted. Both test results of the specimens completed by using the Rotary kiln ash were compared to typical concrete specimens results.

The targeted strength of the final products could be affected by assorted factors, such as aggregate proportioning or incorrect handling of the fresh concrete. This thesis comprises the theoretical research of some significant and crucial ingredients of concrete, which have a considerable impact on concrete strength and grade.

Thesis Commissioner

This thesis was commissioned by Fortum Waste Solution Oy and Lujabetoni Oy. Fortum Waste Solutions Oy is a Nordic company that provides recycling and waste management services for industries, cities, and communities. Fortum Waste Solutions is part of Fortum Corporation.

Lujabetoni Oy is planning to produce durable structure concrete elements by utilizing the Rotary kiln ash as a component of the concrete mixture. Lujabetoni Oy is a company specialized in concrete and has over 65 years of experience in this field.

1.1 Literature review

More than 5,000 years ago, the Egyptians constructed pyramids with an early form of concrete, where mud and straw were mixed into bricks, and mortars were made from Gypsum and Lime (Gromicko & Shepard, n.d.). Also, The Nabataea Traders in southern Syria and northern Jordan discovered the benefits of hydraulic lime which is the cement that hardens underwater and by 700 BC, they were building kilns to provide mortar for the development of rubble-wall homes, concrete floors, and underground waterproof cisterns (Giatec Scientific, 2017). Today concrete involves many ingredients and stages to be eventually produced (Mishra, 2012). However, cement is the component that is playing a vital role in the process of producing concrete when used for binding the concrete material and it is often represented as a soft binding material that, within the presence of water, hardens and has cohesion; as well as gets in touch with properties that modify it to bind the concrete elements along (Gktoday, 2013). Cement Concrete & Aggregates Australia (n.d) and Shyam Steel (n.d) have drawn attention to the fact that coarse aggregate is the other fundamental ingredient, its properties and qualities greatly affecting the properties and quality of the concrete due to its significant proportion of the total volume of the concrete block. Sand is the next crucial component of the concrete mixture that is smaller than 4.75mm in size in the sieve scale. Moreover, sand usually requires some procedures to be done before utilizing it in the mixture depending on the resources where it is gained from, in order to avoid any damages in the concrete product such as efflorescence on the surface and corrosion of reinforcement (Nitterhouse Masonry, n.d). The water is the third component, which plays a critical role in blending, compaction setting, and concrete hardening. Certainly, as Site.Iugaza.Edu.ps (n.d) points out, concrete strength depends directly on the amount of water and its quantity in the mixture. This study experiment utilizing Rotary kiln ash as another component in a concrete mixture. It investigates the potential of gaining durable concrete products, which fit the standards as well as responding to the supposition of economizing several thousand tonnes of conventional aggregate in order to conserve landscapes.

Reference to Herff College Of Engineering, Department Of Civil Engineering (n.d) reveals that the essential ingredients of concrete are almost always the same, but their relative proportioning defines the grade and strength of the concrete. Adopting appropriate ingredients for concrete and calculating their relative proportions for the targeted strength and durability is carried out during a process of mixing the concrete (Ferraris, 2001). The mixing of concrete is usually achieved by either traditional or modern mix as The Cement Sustainability Initiative (n.d) has expressed a similar view, also by the Nykänen method, which was developed in Finland according to Finn sementti (n.d). Furthermore, primary aspects must always be considered based on the characteristics of concrete that differentiate it from other materials, and regarding the financial status, it must be economic and workable per the fresh concrete (Al-Fishawy, 2015). In addition, concrete must be ensured throughout the structural design besides its durability and strength. Reliable concrete must have strength, cohesion, workability, and durability (Portland cement association, n.d). The beneficiary can pursuit various code standards for performing mixture design, for instance, American Concrete Institute (ACI), British Standard (DOE), and Volume method or Basic mix method. Also, in mix design, some critical features are required, such as mean target strength, which can be found and calculated following the formula given in the European standard (EN 206:2014+A2:2021, 2021, pp.38-48), the curve of cement based on its strength, since it is crucial to pick the right cement grade for authoritative concrete strength according to (Vimmrova, 2018), and water-cement ratio. Civil Engineering Hack (n.d) regarding the vital role of the water-cement ratio, it can be stated that the relation between the strength of concrete is to some extent inversely proportional to the ratio of water and cement. Likewise, Haseeb (2017) correctly argues that to achieve the excellent consistency of the concrete, concrete materials need to be appropriately batched or proportioned before producing the concrete. Usually, batching of concrete is done by either weight or volume. The Constructor (n.d) reports that, batching by weight has no uncertainties associated with bulking as an advantage. Furthermore, equipment for batching by weight falls into three categories, manual weigh batching, semi-automatic weigh batching and fully automatic weigh batching. Ritesh (2018) concludes that batching by volume is considered an inaccurate method because the quantities of concrete ingredients to obtain the designed concrete cannot be measured correctly. Yet, after batching, the concrete is required to be mixed by either a central mixer in concrete plants for big projects or by a small mixer for small quantities (Constro Facilitator, 2021). Mixing the concrete inside the mixer has always three stages starting with loading period comprising a dry mix which is achieved by loading the components into the mixer and wet mix after adding the water to the loaded components, the in-between stage is the mixing period, and the last is discharge period (Engr.psu.edu, n.d).

The quantity of cement and water in concrete, size and shape of aggregate, the proportion of concrete, and use of admixture are the factors that influence the workability of concrete at an early age (Suryakanta, 2015). Ce.Memphis.Edu (n.d) makes clear that Early age concrete must have no loss of homogeneity when it is placed, no segregation, and easily finished. Furthermore, the workability of the concrete is usually assets by the slump test (The Constructor, n.d &Cement Concrete.Org, 2020). Kishan (2018) rightly points out that it gives various values referring to how workable the concrete is. Construction Cost (n.d) rightly points out that in early age concrete, it must be ensured that there is no segregation, due to excessed water in the mix. Also, the air content in the concrete must be controlled to avoid damages caused by freezing thaw cycles (Portland Cement Association, 1998 & Corrosion Pedia, 2017).

However, the work of Civil Seek (n.d) indicates that, as hardened concrete, it shall be sufficiently durable for the desired environment exposure for which it is designed as well as strong enough to withstand the load which will be applied to it. The opinion of Shop.Icc Safe.Org (n.d) is that the bending and tensile strength of concrete are usually set between 10% to 20% of the compressive strength which, can be increased by adding reinforcement. The bending and tensile strength can be implemented and calculated by following certain procedures and formulas given in the European standards (EN-13290-5:2019 edition 1, 2019, p.9). Yet, under applied load within a certain time, a potential creep deformation may appear, and it must be avoided (Online Civil Engineering, n.d). In addition, shrinkage, which is a phenomenon that occurs when cracks appear on the surface of the concrete affected by humidity, moisture movement in concrete, type, and shape of coarse aggregates as well as the water-cement ratio (Haseeb, 2017). Lately, the most common measurement for concrete under applied load is the compressive strength which is calculated by certain formula mentioned in the (Bureau of Indian Standard, 2006. 18th Ed, p.21 & EN 12390-3:2019, 2019, p.9) and accomplished following specific procedures mentioned in the European standards (EN 12390-1:2001, 2001, p.9).

1.2 Aims and objectives

This thesis aims to research the utilization of Rotary kiln ash in concrete products, replacing it with coarse aggregates, promoting its use, and improving the recycling economy of waste materials. Also, to save the landscape, bring down the cost of required energy and labor to obtain the conventional aggregate as well as pursue to gain a sturdy concrete product. The thesis also focuses on utilizing the ash in various percentages in the upcoming productions. Furthermore, various tests were be applied on specimens at the ages of 1, 3, 7, 14, and 28 days to point out the performance of the products and their practical usages.

2 Materials and Methods

2.1 Ingredients of concrete

Concrete is basically a mixture of cement, water, fine aggregate, and coarse aggregate in which the cement and water have hardened by a chemical reaction to bind the nearly non - reacting aggregate. The ingredients of the concrete of this study were be modified taking into consideration the utilization of Rotary kiln ash. Additionally, certain meanings can be applied for concrete engineering purposes: paste (Grout) which is a combination of cement and water, the mortar that is derived from paste plus sand and concrete, which is resultant from combining mortar with coarse aggregate.

Table 1 represents the recipe of the concrete mixture of this research including five essential components without any admixture as well as showing the flexibility of Rotary kiln ash according to the utilized quantity of it in the mix trials. In addition, the water-cement ratio is shown as 0,46, which is the elementary value that can be modified in accordance with the targeted strength of concrete.

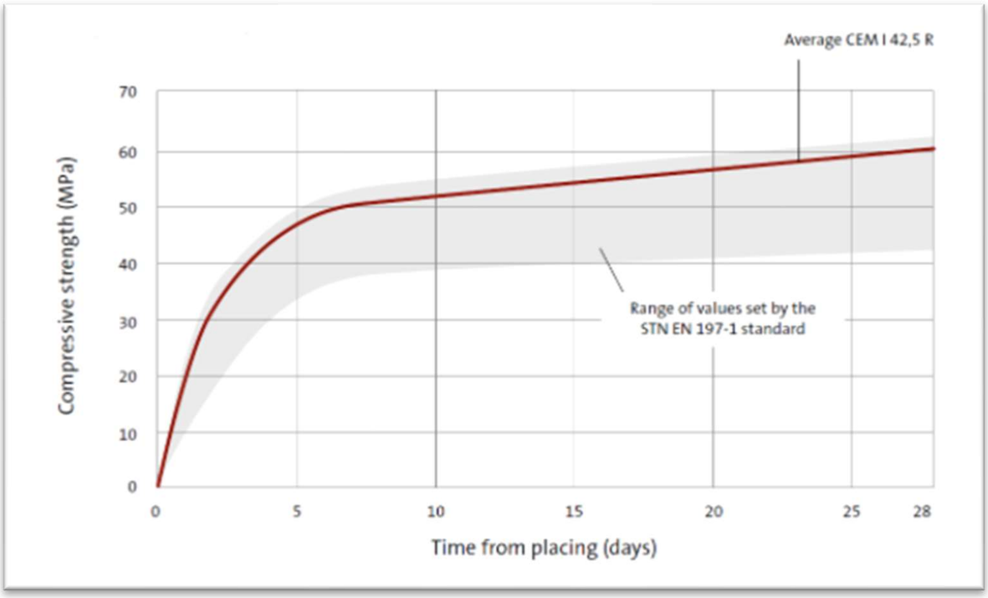
Table 1. Recipe of concrete mixture for ordinary and varied percentages of Rotary kiln ash concrete.

Component of ordinary concrete	Component of Rotary kiln ash concrete	Amount %
Cement	**Cement**	**16**
Water	**Water**	**7.4**
Fine aggregate 0-2mm	**Fine aggregate 0-2mm**	**8.4**
Coarse aggregate 0-8mm	**Rotary kiln Ash 0-8mm**	**± 40.2**
Coarse aggregate 8-16mm	**Rotary kiln Ash 8-16mm**	**± 28**

Cement

Cement refers to the dry powder used for binding the concrete material. It is often represented as a soft binding material that, within the presence of water, hardens and has cohesion and gets in touch with properties that modify it to bind the concrete elements along. However, this study utilized the Embra Rapid- portland cement with a strength of CEM I 42,5 R, which is the high-strength Portland cement for concrete requiring the highest strengths and load of the structure, as well as suitable for concreting in cold weather due to the high development of heat of hydration. This Embra cement allows a speedy demolding of products due to its rapid increase in early strengths. It has good workability, colorfastness, and low volume changes also has high early and final compressive strengths. The proportion of the Embra Rapid- portland cement was fixed in all mix trials.

Figure 1. Increase in strengths CEM I 42,5 R. (Cemmac Cement, 2017)



Coarse aggregate

Coarse aggregate is one of the main concrete components held on the sieve of 4.75 mm and is obtained by grinding different granite forms, hard limestone, and high-quality sandstones. Furthermore, the properties and qualities of the aggregates greatly affect the properties and quality of the concrete, since it comprises a significant proportion of the total volume of the concrete block. Regarding the mix trails and plan of this study, a crushed stone, with particle size varying between 0-16mm was utilized in various percentages concerning the quantity of Rotary kiln ash. The coarse aggregate with the particle size of 0-8 mm had the highest proportion in the recipe of the concrete mixture equal to 40 percent, while the coarse aggregate with the particle size of 8-16mm possesses nearly 30 percent of the recipe. This crushed stone, which has a gruff and untidy surface was replaced according to the recipe of each trial mix.

Fine aggregate

The fine aggregate is the material that is smaller than 4.75mm in size in the sieve scale. Generally, natural sands obtained from pits, rivers, lakes, or seashore are used as fine aggregate. Natural sand is plain to obtain based on the various resources of the natural stands, but some procedures must be done after getting the sand and before using it in any concrete product, depending on fully on the resource. The sand utilized in every mix trail of this study was from the lake, which did not contain chlorides that can cause efflorescence on the surface as well as corrosion of reinforcement.

Water

The water is the only component that reacts chemically with cement as well as plays a crucial role in blending, compaction setting, and concrete hardening. The water temperature was 21C in this study and was mixed with the cement powder to form a paste that holds the aggregates together like glue.

Rotary kiln ash

The Rotary kiln ash used in this study is generated at Riihimäki at Fortum Waste Solutions Oy (FWS) waste incineration plant, which incinerates mainly hazardous waste. A total of about 7,000 tons of ash is generated annually, and the ash is currently being processed at the, FWS Material Treatment Center (iron removal). Furthermore, preliminary research results have shown that the material could be used as an aggregate in concrete industry products.

Figure 2. Rotary kiln ash.

Rotary kiln ash is classified as non-hazardous waste (EWC 19 01 12) according to the European Waste Catalogue.

The solubility test is accredited for soil and waste materials, which is essential to determine the size and polarity of unknown compounds and the presence of acidic and basic functional groups. In addition, the cumulative dissolved solubility test has been done by Fortum Waste Solution following the Finnish standard (CEN/TR16192:2020 en).

Table 2. Cumulative dissolved solubility test for Rotary kiln ash.

Element	Unit	Rotary kiln ash	Measurement uncertainty
Arsenic	mg/kg KA.	0.1	<0.1
Barium	mg/kg KA.	4	<4.0
Cadmium	mg/kg KA.	0.01	<0.01
Chromium	mg/kg KA.	0.1	<0.1

Copper	mg/kg KA.	0.4	<0.4
Molybdenum	mg/kg KA.	0.1	1.6
Lead	mg/kg KA.	0.1	<0.1
Nickel	mg/kg KA.	0.1	<0.1
Antimony	mg/kg KA.	0.05	0.13
Selenium	mg/kg KA.	0.03	<0.03
Vanadium	mg/kg KA.	0.4	<0.4
Zinc	mg/kg KA.	0.8	<0.8
Mercury	mg/kg KA.	0.002	<0.002
Chloride	mg/kg KA.	160	<160
Sulfate	mg/kg KA.	200	<200
Fluoride	mg/kg KA.	2	4.2
DOC	mg/kg KA.	100	<100

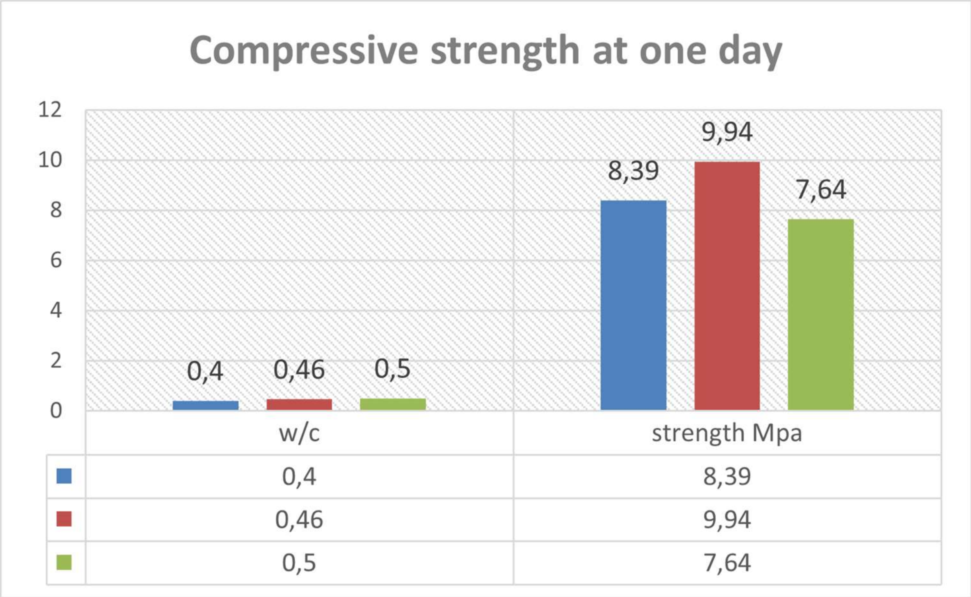
2.2 Batching and mixing of concrete

Batching by weight is more ideal than batching by volume since it is precise and contributes to a more consistent ratio. All materials were therefore weighed by their weight in this study. Nominating the adequate amount of water in the concrete mix was the phase between batching of concrete ingredients and early age concrete.

Selection of water-cement ratio

Based on the vital role that the water-cement ratio plays in the compressive strength of the concrete, it was mandatory to pick up the right ratio concerning the final preferable compressive strength results for the products. However, three concrete mix trails utilized different water-cement ratios as well as three (3) concrete specimens utilized 45% of Rotary kiln ash accomplished and tested for compressive strength at the age of one (1) day.

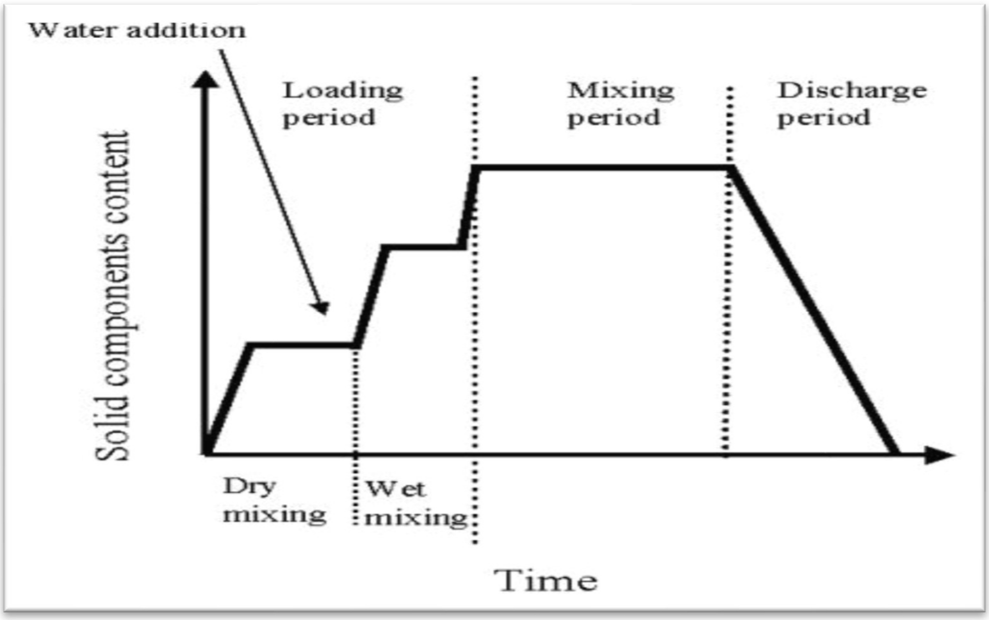
Figure 3. Compressive strength of specimens produced by utilizing different W/C ratios.



Mixing of concrete

This study's mixing of concrete falls into three stages as shown in Figure 3. starting with the loading period, which contains a dry mix which is the batching of all ingredients together by using a batch mixer and wet mix after adding the water into the mix. The second stage was the mixing period, which is the duration of time it takes to mix concrete, once the mixer is fully charged with all the materials. Furthermore, the discharge period, which is the last stage was arranged to keep the homogeneity of the concrete as well as to increase its productivity.

Figure 4. Stages of concrete mixing. Ferraris, Chiara F. (2001, volume 106, p.395).



2.3 Early age- concrete

Workability

According to the American Concrete Institute (n.d), the definition of workability of the concrete is the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished. Furthermore, the fresh concrete of this study is considered workable following the accomplishment of the conditions below:

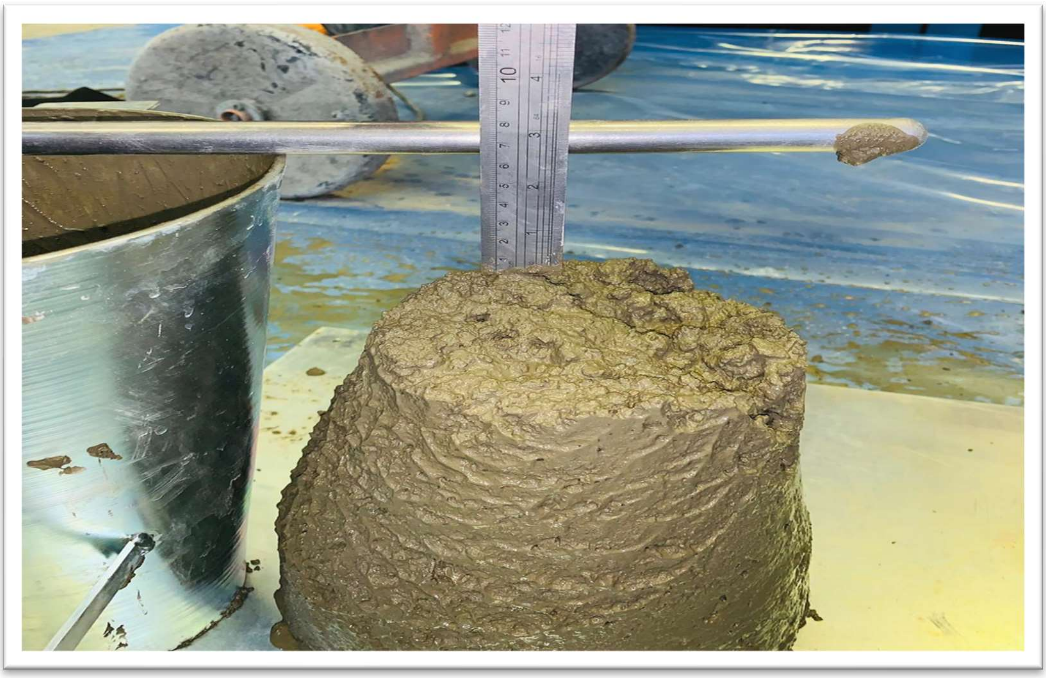
- No loss of homogeneity when it is placed.
- It was compacted with specified effort.

- No segregation.
- Easily finished.

Consistency (Slump test)

The slump test was achieved at the Laboratory to assess the workability of our concrete mix, and it was conducted at the beginning of the concrete operation. It was accomplished following the European standard (EN 12350-2:2019 edition 1). However, the entire surface of the mold was totally clean of moisture and any hardened concrete before the implementation of the test. Also, the mold was placed on a horizontal, rigid, non-observant, and smooth surface, and four layers filled with an approximate thickness of ¼ of the height of the mold. Each layer was tamped at least 25 times just to ensure that the strokes are uniformly distributed over the cross-section as well as the trowel used to level the tamped last layer and confirmed that the mold is filled exactly to the top.

Figure 5. Measurement of concrete slump.



The mold was then removed by rising it gradually and this operation was carried out without any vibration or jerks and within two minutes after finishing the final tamping. However,

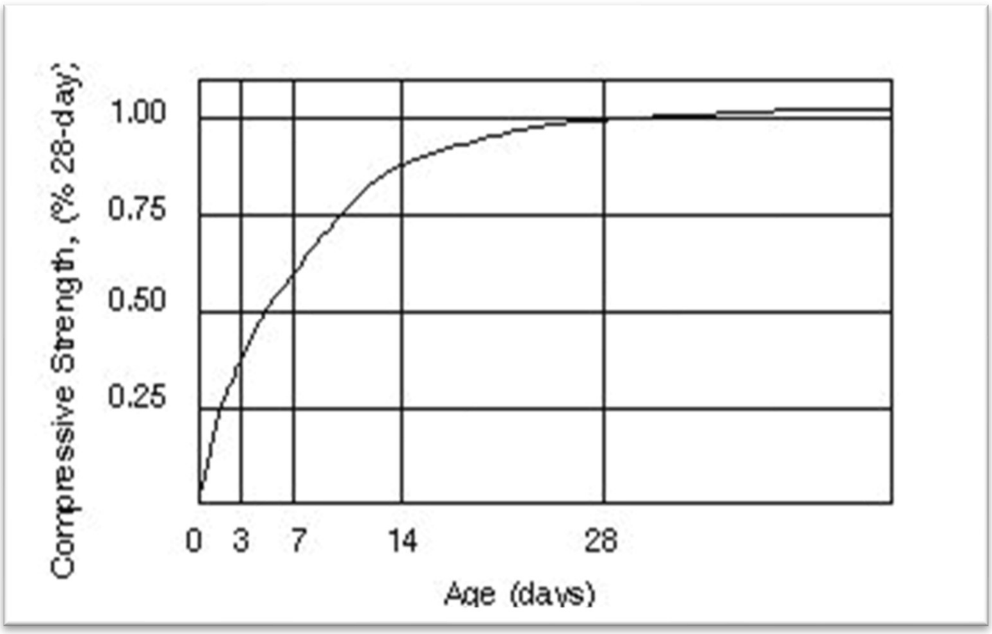
Figure 5. shows the true slump which is the desired form of a slump that must be obtained for Rotary kiln ash and ordinary mix trial, which in turn ensures the uniformity of the batch. In addition, it refers to the workability of concrete that is used for non-reinforced and normally reinforced concrete.

2.4 Hardened concrete

Strength of concrete

Concrete is very strong in compression but relatively weak in bending and tension. Furthermore, compressive strength measured by Mpa it is also affected by the cement water ratio and depends on the type and quantity of cement in the mixture. The bending and tensile strength of concrete sets between 10% to 20% of the compressive strength but it can be increased by adding reinforcement. However, concrete specimen usually gains its strength gradually, for instance at the age of one (1) day it gains 16% of its full strength, and at age of fourteen (14) days, it gains 90% of its full strength as shown in Figure 6. This study completed two different types of tests, which are the compressive strength test and flexural strength test.

Figure 6. Typical strength-gain curve. (Civil Engineering, n.d)



Compressive strength test

The compressive strength of the concrete specimen is determined by continuous loading on the cylinder specimen until failure. Moreover, Figure 8. shows a compression testing machine, which is usually used for the evaluation. A compression testing machine works by applying a compressive pressure load to determine material behaviors as well as to measure different properties of materials such as elastic limits, proportional limit, yield point, yield strength, etc. Similarly, the compressive strength of concrete is the load at which the specimens collapse and the unit for this strength is a mega-pascal (MPa). The compressive strength is calculated by the following formula:

$$\mathbf{Fc = F/Ac}$$

Where

Fc= The compressive strength, in Mpa (N/mm2)

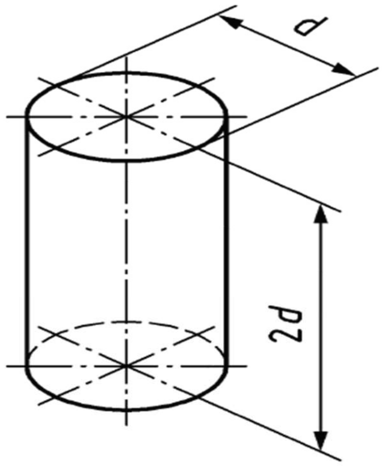
F= The maximum load at failure in N

Ac= The cross-sectional area of the specimen in which the compressive force acts, in mm2.

The test results are used to guarantee that the concrete mixture meets the requirements of the specified strength, Fc. The beneficiary can utilize the Compressive strength test results for quality control, acceptance of concrete, and assumption of concrete strength in structure. However, two different types of concrete specimens, cubes, and cylinders, can be used as concrete specimens.

This research is planned to have a compression test for the specimens at the desired percentage of the ash to achieve a precise result and based on the behavior of concrete with obtaining its strength gradually. Likewise, the tests are set to be accomplished at the age of (1 day, 3 days, 7 days, 14 days, 28 days). The specimens are cylindrical as shown in Figure 7. with dimensions of 300mm height and 150 mm width following the European standard (EN 12390-1:2001, 2001, p.10).

Figure 7. Nominal size of a cylinder specimen. (EN 12390-1:2001, 2001, p.10)



d, mm	100	113 [a]	150	200	250	300
[a] This has a load-bearing area of 10 000 mm^2.						

Procedures implemented for the compressive strength test:

- The concrete specimen used has not been dried out before testing and kept in molds for 24 hours and then in water for curing.
- The weight of specimens was recorded.
- Ensured that the bearing surface of the test machine was clean.
- Specimens were placed in the center of the machine and the ends of specimens were not departed from perpendicularity with the cylinder axis by more than 0.5 degrees.
- The maximum load is noted, as well as any unusual features were recorded.

Figure 8. Compression test machine.

The compression test stage included five (5) phases distributed in accordance with the age of the specimens. Each specimen in every phase was produced by utilizing a constant of 0,46 as a water-cement ratio. Phases, one at the age of one day, two at the age of three days, and three at age of seven days had five specimens for each. Specimens were produced by utilizing 25%, 45%, 55%, 75%, and 100% of Rotary kiln ash. Phases four and five had six specimens for each. Also, the two specimens involved were produced by utilizing the usual aggregate alongside the specimens produced by utilizing 25%, 45%, 55%, 75%, and 100% of Rotary kiln ash.

Flexural strength test

The flexural strength/ Modulus of the rapture of concrete is a measure of the tensile strength of the concrete, it is a measure of unreinforced beam or slab concrete to resist failure in bending. However, flexural strength is usually about 10 to 20 percent of the compressive strength of the concrete depending on the size, volume, and type of coarse aggregate. Usually, the importance of this test belongs to the acceptance of pavements by the designers of pavements as well as some designers use the flexural strength for field control. Furthermore, it is the test which, refers to, how much applied force the specimen will deflect as well as how much the displacement will be. The specimen is usually a beam which the setting has certain conditions that have been taken into consideration as Figure 7 shows. Moreover, calculating the flexural strength of the specimen was following the formula given in the European standard (EN-13290-5:2019 edition 1, 2019, p. 10).

Figure 9. Arrangement of loading of test specimen (two-point loading). (EN-13290-5:2019 edition 1, 2019, p.10)

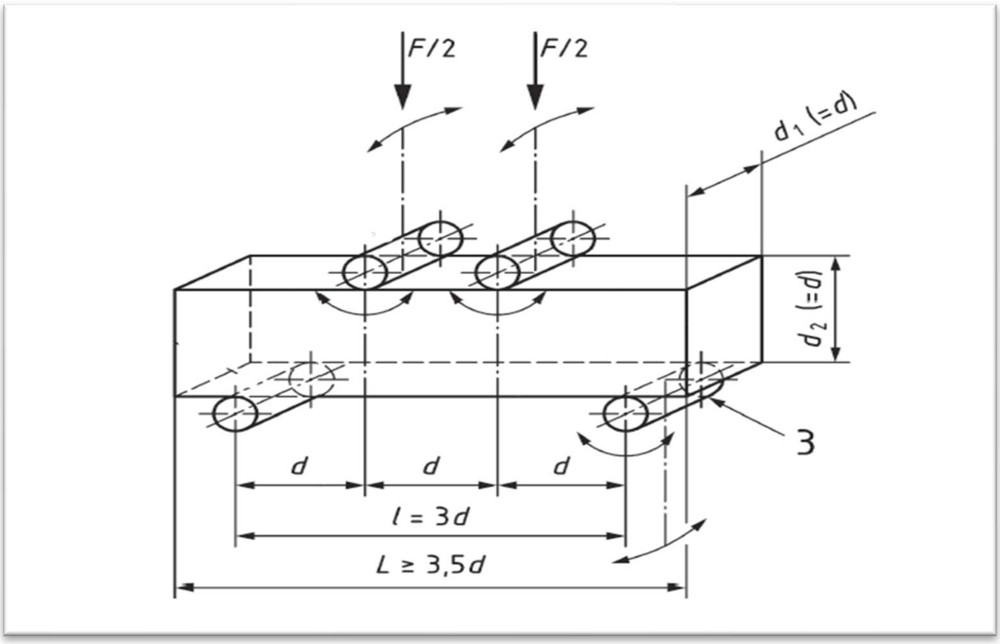


Figure 9. above clearly shows that the dimensions of the height, as well as the width of the specimen, are the same and the span is three and half times the width.

Yet, the flexural strength of any specimen (molded and curing following the same standard and figure above) can easily be calculated following the formula:

$$Fct,fl= F*L/d1*d2^2$$

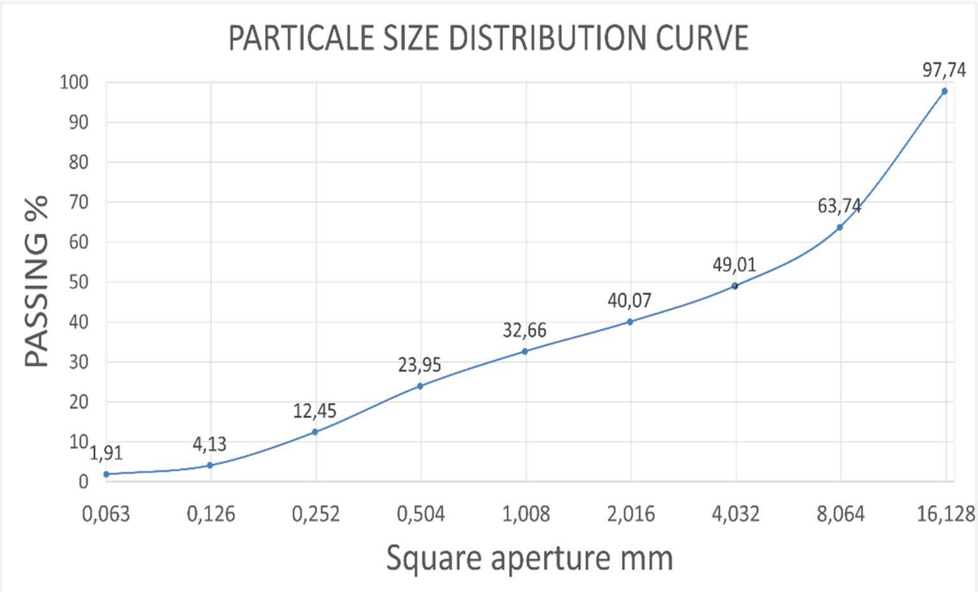
Where

Fct,fl	is the flexural strength in MPa (N/mm2).
F	is the maximum load in N.
L	is the distance between lower roller, in mm.
d1and d2	are the lateral dimensions of the specimen, in mm.

3 Results

The sieve analysis for aggregate and ash was done at Hamk Metal Sheet Centre following the (EN 933-1:2012) European standard. The particle size distribution curve is presented below in Figure 10. The workability of fresh concrete is reviewed according to the requirement of obtaining workable concrete. As hardened concrete, the shrinkage/ cracks on the surface of the specimens did not appear due to the utilization of appropriate type, shape of coarse aggregates/ash, and water-cement ratio. The ideal failure shape exhibited for concrete specimens tested in this study are shown progressively considering the ash percentages utilized in the concrete mix. Furthermore, the weights and compressive strength at 1, 3, 7, 14, and 28 days of specimens produced by utilizing the Rotary kiln ash and typical ingredients are presented progressively.

Figure 10. The particle size distribution curve of Rotary kiln ash and aggregates.



3.1 Workability of mixture trials

This study mix trials utilized a 0,46 water-cement ratio regardless of the percentages of Rotary kiln ash. The fresh concrete of every trial had no segregation, was easily finished, and had homogeneity when it was casting in the molds. In another word, samples that took from different places in the mixer contain the individual components of the mixture in equal percentages, also the cement paste and aggregate/ash did not separate from each other. However, according to the European standard (EN-12350-2:2019 edition 1) the slump test is achieved for all mix trials to observe the consistency of the concrete. Table 3 below shows each trial slump test result and its consistency.

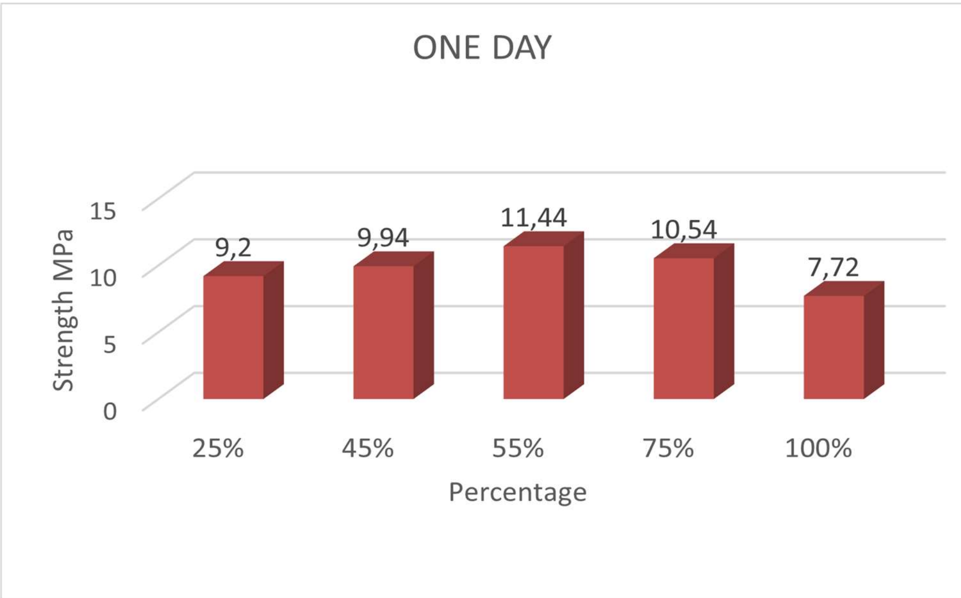
Table 3. Slump test and consistency of fresh concrete.

Mix Trial/Ash percentage	Slump test/mm	Consistancy
0%	102	High workability
25%	58	Medium Workability
45%	65	Medium Workability
55%	42	Plastic
75%	41	Plasic
100%	51	Medium Workability

3.2 Compressive strength at one day

This study phase included five (5) concrete specimens. Compression tests were accomplished one day after the casting. As illustrated in Figure 11. the specimen produced by utilizing 25% Rotary kiln ash obtained 9,2 MPa compressive strength, which increased to 9,9 MPa when a specimen of 45% Rotary kiln ash was tested. The figure also shows that the maximum value of 11,4 MPa is obtained for the specimen of 55% Rotary kiln ash. In the case of specimen utilizing 75% of Rotary kiln ash, the compressive strength decreases a little compared to 55% ash to be 10,5 MPa until it reaches the minimum value of 7,7 MPa obtained for specimen produced by only Rotary kiln ash.

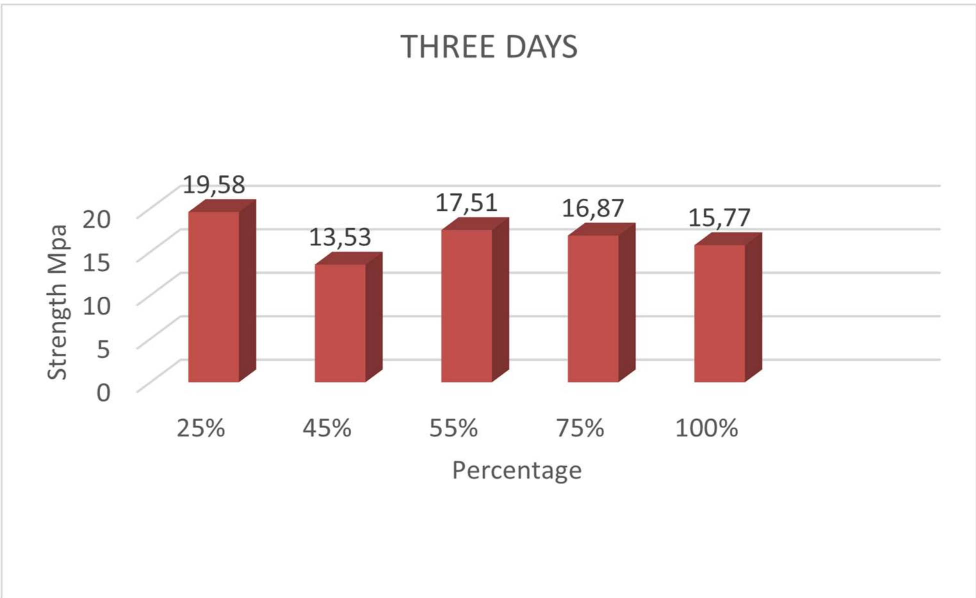
Figure 11. The compressive strength at one day.



3.3 Compressive strength at three days

This second phase of the study has also been considered to have five (5) concrete specimens. The compressive strength test was completed at the age of three days. Following the results of Figure 12, it is shown that at the age of three days a 19,6 MPa is the maximum compressive strength of the specimen produced by utilizing 25% ash and the minimum is 13,5 MPa for specimen obtained from mix trial contains 45% of Rotary kiln ash. Also, 17,5 MPa, 16,8 MPa, and 15,7 MPa are convergent compressive strength of specimens produced by utilizing 55%, 75%, and 100% of Rotary kiln ash respectively. Furthermore, it is noted that the compressive values are increasing compared to the values obtained from one day phase.

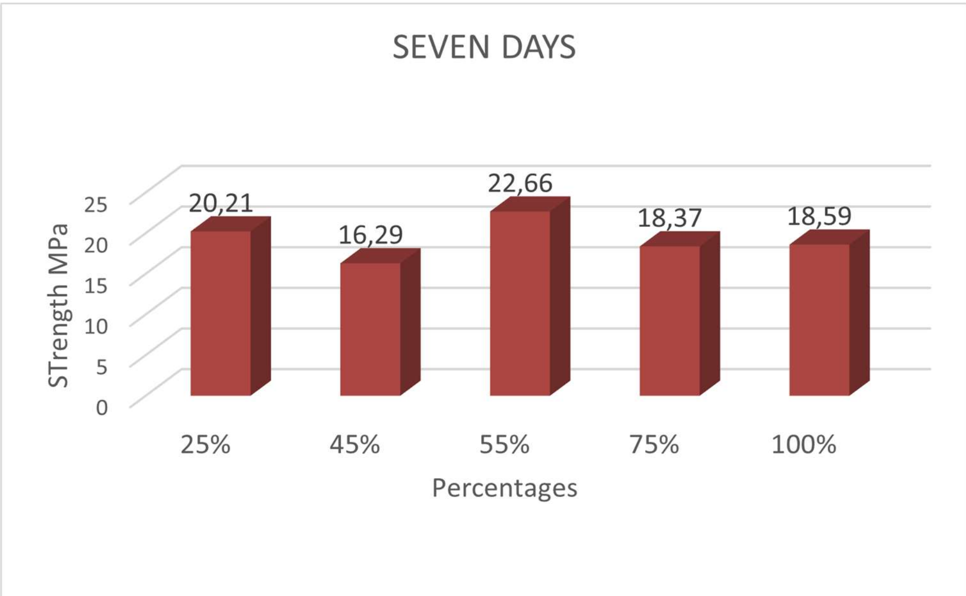
Figure 12. The compressive strength at three days.



3.4 Compressive strength at seven days

This study phase also involved five (5) specimens that, were tested for compressive strength at the age of seven days and obtained a higher result than at the age of three days. As shown in Figure 13, the compressive strength of 45 % utilized ash specimen is considered as the minimum obtained value of 16,3 MPa compared to the rest of the specimens tested at the same age. Specimens of 75% and 100% utilized ash obtained almost the same value, which is 18,4 MPa and 18,6 MPa respectively. The increase of the compressive strength of 20,2 MPa is obvious concerning the specimen of 25% utilized ash until it reaches the maximum value of 22,7 MPa for the specimen produced by utilizing 55% of Rotary kiln ash.

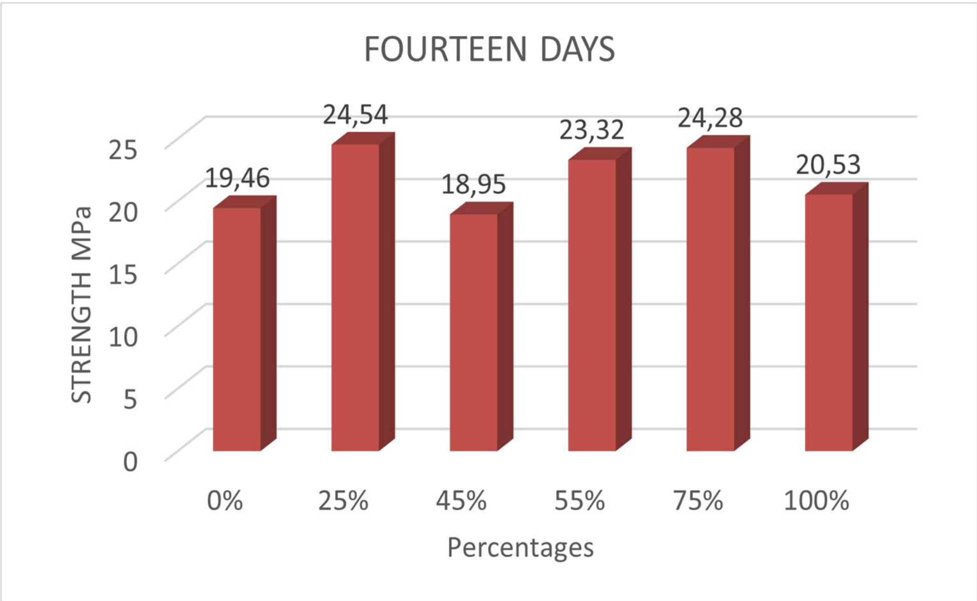
Figure 13. The compressive strength at seven days.



3.5 Compressive strength at fourteen days

The specimens amount in this trial was set to be six (6) for testing the compressive strength at age of fourteen days. From Figure 14, the specimen contains 45% of Rotary kiln ash gained 18,9 MPa, which is the lowest result compared to the rest of the results. However, the increase of the result is notable starting with 19,4 MPa for the ordinary concrete specimen, 20,5 MPa for specimen utilized only Rotary kiln ash, 23,3 Mpa for specimen utilized 55% Rotary kiln ash, and 24,3 MPa for specimen produced by utilizing 75% Rotary kiln ash until it reaches the maximum compressive strength of 24,5 MPa obtained for 25% Rotary kiln ash specimen.

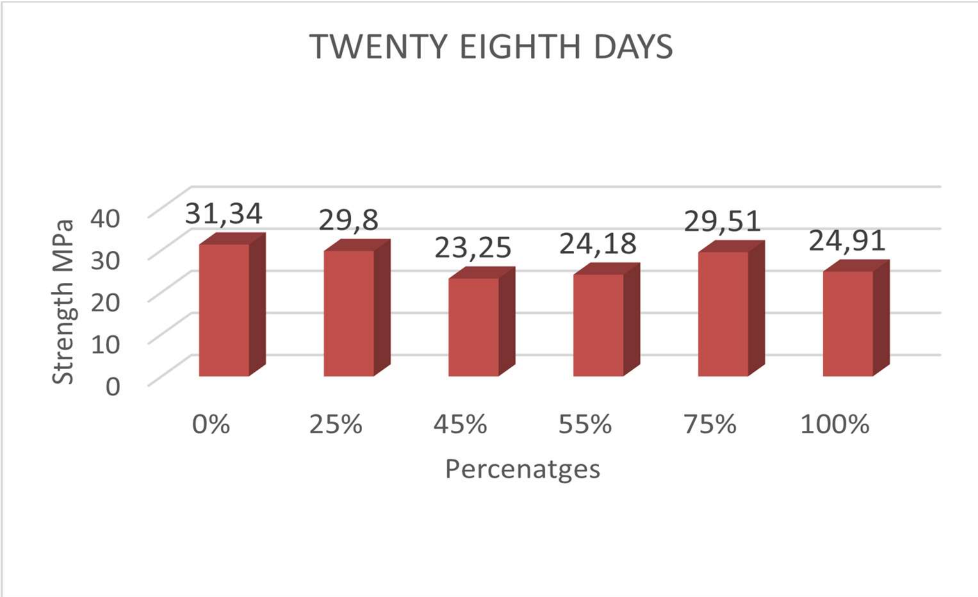
Figure 14. The compressive strength at fourteen days.



3.6 Compressive strength at twenty eighth days.

The last phase of this stage of the study comprised six (6) specimens. The compression test was achieved 28 days after casting. However, despite that, the compressive strength values of the specimens were varying from each other. The values were between the range of 23 MPa and 31 MPa.

Figure 15. The compressive strengths at twenty-eight days.

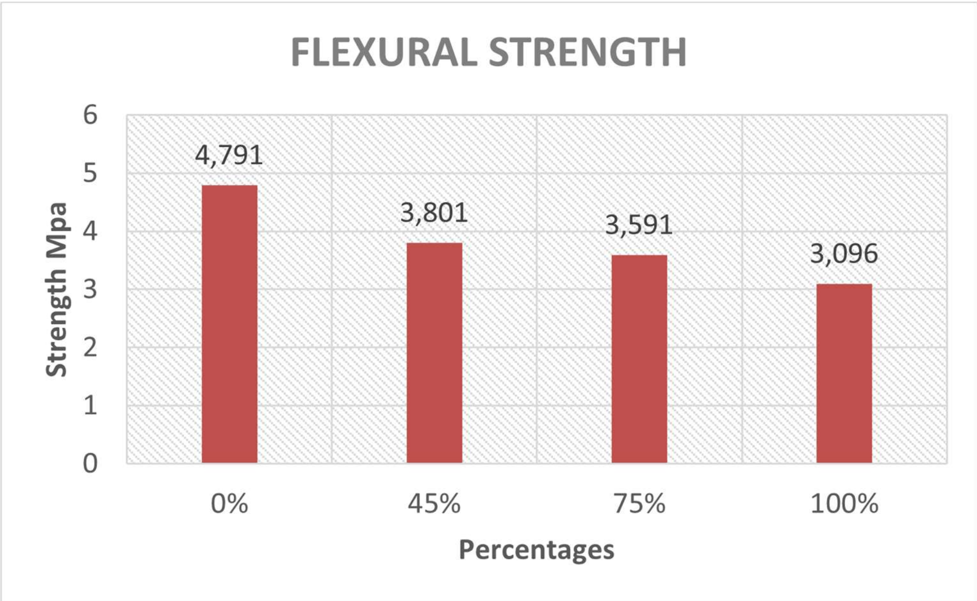


The values in Figure 15 articulate the mean compressive strength of specimens. The test result indicates that the obtained compressive strength of zero ash/ordinary concrete specimen is 31,3 MPa as a mean compressive strength for a cylindrical specimen, which is more than the required mean compressive strength for C25/30 concrete class. The 29,8 MPa and 29,5 Mpa compressive strength for cylindrical specimens produced by utilizing 25% and 75% of Rotary kiln ash were higher than the required mean value for concrete strength class C25/30. Furthermore, this result illustrates that 24 MPa as a mean value obtained from trial of 45%, 55%, and 100% Rotary kiln ash for cylindrical specimens is equal to the required minimum mean compressive strength of C20/25 concrete class.

3.7 Flexural strength at twenty eighth days

Grading the concrete of this research required an inspection of the modulus of rupture in order to compare the obtained result with the results of ordinary concrete. However, four (4) specimens varying with different percentages of ash were molded and tested following [43.] at the age of 28 days.

Figure 16. The flexural strengths at twenty-eight days of tested specimens with varying amounts of ash.



Results are uneven regarding the utilized ash percentages as shown in Figure 16. The maximum value was obtained for the ordinary concrete specimen with a magnitude of 4,8 MPa, and then it decreased to 3,8 MPa for the specimen of 45% ash and 75% ash specimen gained only 3,591 MPa until it reached the minimum value for the specimen of 100% ash (3,096 MPa). Similarly, it is shown that the flexural strength of the specimens decreases as much as the ash percentage in the concrete mix trial increase.

However, regarding the ordinary concrete specimens, the results indicated that the compressive strength at 28 days is almost 40 percent higher than at the age of 14 days. 4,8 MPa flexural strength was the highest compared to the rest of the values, which means that ordinary specimens can resist the applied load more than specimens produced by utilizing Rotary kiln ash. The 25 percent ash category obtained various compressive strengths regarding the age of the specimens as well as the compressive strength is gradually increasing from 9,2 MPa at the age of one day, 24,5 MPa at age of 14 days, which is equal to 82 percent of the maximum value 29,8 MPa at the age of 28 days. It is visible that 45 percent ash series compressive strength has a disparity results concerning the gradual concrete strength gain that began with 9,9 MPa at the age of one day and 18,95 MPa at the age of 14 days which is 81 percent of 23,25 MPa the strength of the specimen at age of 28 days. In addition, 45 percent ash characterized that it had a specimen tested for flexural strength, which obtained 3,801 MPa, as a result, referring to that it is less resistant to bending than ordinary concrete. Furthermore, the compressive strength results of the category of 55 percent ash are as well displaying a progressive increase starting with 11,44 MPa at age of one day, 22,66 MPa at age of seven days, and 23,32 MPa at age of 14 days which in turn equal to 96 percent of the 24,18 MPa compressive strength at age of 28 days. Considering the 75 percent ash category, it is plausible that the compressive strength is boosting reliably from one day with 10,45 MPa as a minimum and 24,28 MPa at age of 14 days which is equivalent to 82 percent of the maximum 29,51 MPa at twenty-eight days. The 3,591 MPa flexural strength of 75 percent is indicating that the specimen has lower resistance in bending compared to the ordinary and 45 percent ash specimens. Ultimately, the category of specimens produced by utilizing only ash instead of aggregate indicates significant progress in the specimens compressive strength initiated with 7,72 MPa at age of one day, 18,59 MPa at age of seven days, and 20,53 MPa at age of fourteen days which also equal to 82 percent of the compressive strength 24,91 MPa at age of twenty eight days. Regarding the flexural strength of the category of 100 percent ash, it is obvious that the 3,096 MPa is the minimum obtained flexural strength compared to the rest of the specimens, which in turn means the least bending resistance.

4 Conclusions

This work demonstrated that concrete with the strength class of C20/25 with the minimum cylinder compressive strength of 20 MPa can be provided by utilizing either 45%, 55%, or 100% of Rotary kiln ash. This work also demonstrated that concrete with a strength class of C25/30 with the minimum cylinder compressive strength of 25 MPa can be supplied by utilizing 25% or 75% of Rotary kiln ash. This investigation revealed that utilizing typical ingredients in concrete mix will donate the same concrete grade obtained by utilizing 25% or 75% of the Rotary Kiln ash. This study also showed that utilizing 45%, 55%, and 100% of the Rotary kiln ash in the concrete mix which contains Embra Rapid- Portland cement (CEM I 42,5 R) and without any admixture will award a concrete strength class of C20/25. The Concrete class C20/25 is the minimum concrete strength class recommended for the construction of reinforced load-bearing building structural members such as beams, columns, and slabs in mild exposure condition, also used for domestic floors and foundations and it is good for workshop bases, garages, driveways, and internal floor slabs.

5 Suggestions for future research

This study has implemented the most crucial tests regarding the strength of concrete. Other vital tests are recommended to be completed in accordance with obtaining a better view of the behavior of the products. In this regard, this thesis suggests completing the freezing and thawing test, achieving the modulus of elasticity of the Rotary kiln ash, and utilizing cement with higher strength.

5.1 Implement freezing and thawing test

Freeze-thaw resistance can be defined as the ability to resist a destructive force of cyclic freezing and thawing. Water constantly drains into cracks during the freezing process. When the water freezes and expands at low temperatures, the crevices of the concrete and any fractured concrete are under enormous pressure. If the pressure exceeds the tensile strength of the concrete, the gap in the concrete in which the frozen water accumulates is dilated and ruptured and, consequently, the cracks multiply within the structure. D-cracks are the cracks that appear on the concrete elements caused by the freezing and thawing behavior of concrete. However, this study suggests carrying out the freezing and thawing test according to what was mentioned above and in accordance with the assessment of this concrete as durable and safe to be utilized as a concrete structural element.

5.2 Achieve modulus of elasticity of Rotary kiln ash

According to the fact that modulus of elasticity of concrete is a crucial factor in designing concrete structures, and the modulus of elasticity of concrete relies on the modulus of elasticity of the concrete ingredients and their mixture ratios. Therefore, the modulus of elasticity of Rotary kiln ash is suggested to be achieved.

5.3 Use of The Cemex Rapid- Portland cement 52,5 R

Regarding the effect of the strength of the cement on the final compressive strength of the concrete and in order to gain a higher compressive strength for the concrete product a Cemex Rapid- Portland cement with a strength of 52,5 R is proposed to be used. Cemex Rapid- Portland cement 52,5 R is proposed because it increases the production rate of precast units by allowing the earlier stripping of molds, assists in counteracting the effects of cold weather, and is compatible with chloride requirements for prestressed concrete.

References

Al-Fishawy, F. (2015). Building Materials Technology: Concrete. Retrieved May 21, 2021, from https://cupdf.com/document/lecture-5-concrete-aalto-lecture-5-concrete-2-aci-2111-91-concrete.html.

American Concrete Institute (n.d). Technical Questions- Consistency, plastic consistency, and workability. Retrieved Jun 27, 2021, from https://www.concrete.org/tools/frequentlyaskedquestions.aspx?faqid=647.

Bureau of Indian Standard. Methods of Tests for Strength of Concrete (2006. 18th Ed). New Delhi. http://www.iitk.ac.in/ce/test/IS-codes/is.516.1959.pdf.

CEN/TR 16192:2020 en. (2020). Waste. Guidance on analysis of eluates. SFS Online.

Ce.Memphis.Edu. (n.d). Part 8 - Fresh Concrete. Retrieved Jun 17, 2021, from http://www.ce.memphis.edu/1101/notes/concrete/everything_about_concrete/08_fresh.html.

Cement Concrete & Aggregates Australia. (n.d.). Concrete Basics: A guide to concrete practice. https://www.ccaa.com.au/imis_prod/documents/ConcreteBasics.pdf.

Cement Concrete.Org. (2020). Slump Test of Concrete, slump cone for Workability – Procedure, Apparatus. Retrieved Jun 21, 2021, from https://cementconcrete.org/how-to-guide/concrete-slump-test/2171/.

Cemmac Cement. (2017). CEM I 42,5 R, Portland cement. Retrieved August 9, 2021, from http://www.cemmac.sk/dev/language/en/cement-cem-i-425r-2/.

Civil Engineering Hack. (n.d). IS Method For Concrete Mix Design. Retrieved Jun 12, 2021, from https://civilhack.blogspot.com/2016/07/is-method-for-concrete-mix-design.html.

Civil Engineering. (n.d). Properties of Concrete. Retrieved Jun 18, 2021, from http://www.ce.memphis.edu/1101/notes/concrete/section_3_properties.html.

Civil Seek. (n.d). Properties of Hardened Concrete; A Detailed Guide. Retrieved July 10, 2021, from https://civilseek.com/properties-of-hardened-concrete/.

Concrete in Practice. (n.d). CIP 16- Flexural strength concrete. https://www.crmca.com/wp-content/uploads/2016/08/CIP-16-Flexural-Strength-Concrete.pdf.

Constro Facilitator. (2021, April 15). Different Types of Concrete Mixers. Retrieved Jun 15, 2021, from https://www.constrofacilitator.com/different-types-of-concrete-mixers/.

Construction Cost. (n.d). Segregation of concrete- causes and remedies. Retrieved July 9, 2021, from https://constructioncost.co/segregation-of-concrete.html.

Corrosion Pedia. (2017, August 25). Freeze-Thaw Resistance. Retrieved August 2, 2021, from https://www.corrosionpedia.com/definition/5526/freeze-thaw-resistance.

Diamond.S. in Durability of Concrete and Cement Composites, 2007. Retrieved April 12, 2021, from https://www.sciencedirect.com/topics/materials-science/cement-hydration

EN 12350-2:2019 edition 1. (2019). Testing of fresh concrete. part 2: Slump test. SFS Online.

EN 12390-1:2001.(2001). Testing hardened concrete. part 1: shape, dimension and other requirements for specimens and moulds. SFS Online.

EN 12390-3:2019. (2019). Testing hardened concrete. Part 3: Compressive strength of test specimens. SFS Online.

EN 13290-5:2019 edition 1.(2019). Testing hardened concrete. part 5: Flexural strength of test specimens. SFS Online.

EN 206:2014 + A2:2021. (2021). Concrete, specification, performance, production and conformity-clause 8.2 Conformity control for designed concrete. SFS Online.

EN 206:2014+A2:2021.(2021). Requirements for hardened concrete. Compressive strength-clause 5.5.1.2. SFS Online.

EN 933-1:2012. (2012). Test for geometrical properties of aggregates. Part 1: Determination of particle size distribution. Sieve method. SFS Online.

Engr.psu.edu.(n.d). Mixing and Transporting Concrete. Retrieved Jun 15, 2021, from https://www.engr.psu.edu/ce/courses/ce584/concrete/library/construction/mixingtransport/mixingandtransporting.html.

Ferraris, Chiara F. (2001, volume 106, p.395). Concrete mixing methods and concrete mixers: state of the art. United States: The Journal of Research of the National Institute of Standards.

Finn sementti. (n.d). Arvo Nykänen, talven taitaja ja suhteituksen isä. Retrieved June 1, 2021, from https://finnsementti.fi/yritys/historia/arvo-nykanen-talven-taitaja-ja-suhteituksen-isa/.

Giatec Scientific. (2017, July 28). The history of Concrete. Retrieved May 23, 2021, from https://www.giatecscientific.com/education/the-history-of-concrete/.

Gktoday. (2013, May 22). What are the different grades of Cement?. Retrieved May 25, 2021, from https://www.gktoday.in/gk/cement/.

Gromicko, Nick & Shepard, Kenton (n.d). The History of Concrete. Retrieved May 22, 2021, from https://www.nachi.org/history-of-concrete.htm.

Haseeb, Jamal. (2017, March 18). Batching, Mixing, Placing and Compaction of Concrete. Retrieved Jun 13, 2021, from https://www.aboutcivil.org/batching-mixing-placing-compaction-of-concrete.html.

Herff College Of Engineering. Department Of Civil Engineering. (n.d). Properties of concrete. Retrieved August 31, 2021, from http://www.ce.memphis.edu/1101/notes/concrete/section_3_properties.html.

Kishan, Mudavath. (2018, April 5). What is slump & It's types, Values for various construction work. Retrieved Jun 22, 2021, from https://wecivilengineers.wordpress.com/2018/04/05/what-is-slump-its-types-values-for-various-construction-work/.

Mishra. P.S & Chandrakar.J.K (2012, March 1). Comparison of IS, BS and ACI Methods of Concrete Mix Design and Proposing Function Equations Based Design. Basic ingredient of Concrete, 4-5.

Nevada Ready Mix. (n.d). Testing the compressive strength of Concrete. Retrieved April 15, 2021, from https://www.nevadareadymix.com/concrete-tips/testing-the-compressive-strength-of-concrete/.

Nitterhouse Masonry. (n.d). What Is Efflorescence and How to Remove It. Retrieved June 23, 2021, from https://www.nitterhousemasonry.com/tips-advice/what-is-efflorescence//.

Online Civil Engineering. (n.d). Creep Of Concrete. Retrieved July 12, 2021, from http://civil-online2010.blogspot.com/2015/02/creep-of-concrete.html.

Port-land cement Association. Design and Control of Concrete Mixtures. 16th ed. 5420 Old Orchard Road.

Portland Cement Association. (1998, April). Control of Air Content in Concrete. https://www.cement.org/docs/default-source/fc_concrete_technology/pl981.pdf.

Ritesh Patel. (2018, September 7). What is Volumetric Batching of Concrete?. Retrieved Jun 14, 2021, from https://gharpedia.com/blog/volumetric-batching-concrete-2/.

Setzer, M. J. G. Fagerlund and D. J. Janssen. (1996, Novomber 29). Freeze-CDF Test – Test method for the freeze-thaw resistance of concrete - tests with sodium chloride solution (CDF). https://www.rilem.net/images/publis/119303.pdf.

Shop.Icc Safe. Org. (n.d). Chapter 3 - The Strength of Concrete. https://shop.iccsafe.org/media/wysiwyg/material/9090S15-Sample.pdf.

Shyam Steel. (n.d.). Coarse Aggregate in Concrete Construction. Retrieved May 27, 2021, from https://shyamsteel.com/blogs/coarse-aggregate-in-concrete-construction/.

Site.Iugaza.Edu.ps. (n.d). Chapter 7: Concrete Mix Design. http://site.iugaza.edu.ps/malqedra/files/7-Mix-design.pdf.

Suryakanta. (2015, October 29). 3 Methods Of Determining Workability Of Concrete. Retrieved Jun 17, 2021, from https://civilblog.org/2015/10/29/3-methods-of-determining-workability-of-concrete/.

The Cement Sustainability Initiative. Recycling concrete. Geneva, Switzerland. World Business Council for Sustainable Development.

The Constructor. (n.d). Concrete Slump Test. Retrieved Jun 22, 2021, from https://theconstructor.org/practical-guide/tests-workability-of-concrete-site-values/5150/.

The Constructor. (n.d). Methods of batching concrete. Retrieved Jun 14, 2021, from https://theconstructor.org/concrete/concrete-batching-methods/26514/.

Vimmrova A, Vyborny J, vysoke C. (2002. 2018).Building materials 10. Materials and Testing Methods. 1st ed. Praha: Vydavatelství ČVUT

Appendix 1: Sieve analysis and Typical specimens

1. **Sieve analysis**

Sieve analysis was achieved at HAMK Metal Sheet Centre following the European standard (EN 933-1:2012, 2012) and by using the sieve machine. However, Table 4. below shows the values concerning the sieve analysis test.

Table 4. Sieving result of Ash and aggregate.

Sieve Number	Diameter (mm)	Soil retaned (gm)	CUMULATIVE WEIGHT RETAINED (gm)	CUMULATIVE % WT.RETAINED	CUMULATIVE % WT. PASSING
#16 mm	16.00	22,56	22,56	2,26	97,74
#8 mm	8.00	340,00	362,56	36,26	63,74
#4	2.00	147,30	509,86	50,99	49,01
#2	0,85	89,49	599,35	59,94	40,07
#1	0.43	74,10	673,45	67,35	32,66
#0.500	0.25	87,04	760,49	76,05	23,95
#0.250	0.075	115,00	875,49	87,55	12,45
#0.125	0.125mm	83,20	958,69	95,87	4,13
#0.063	0.063mm	22,17	980,86	98,09	1,91
Pan		19,14	1000,00	574,33	

2. Typical specimens

Table 5. Recipe of the ordinary concrete mixture.

Component	Amount %
Cement	16
Water	7.4
Fine aggregate 0-2mm	8.4
Coarse aggregate 0-8mm	40.2
Coarse aggregate 8-16mm	28

I. Compressive strength test

Table 6. Compressive strength and weight of typical specimens.

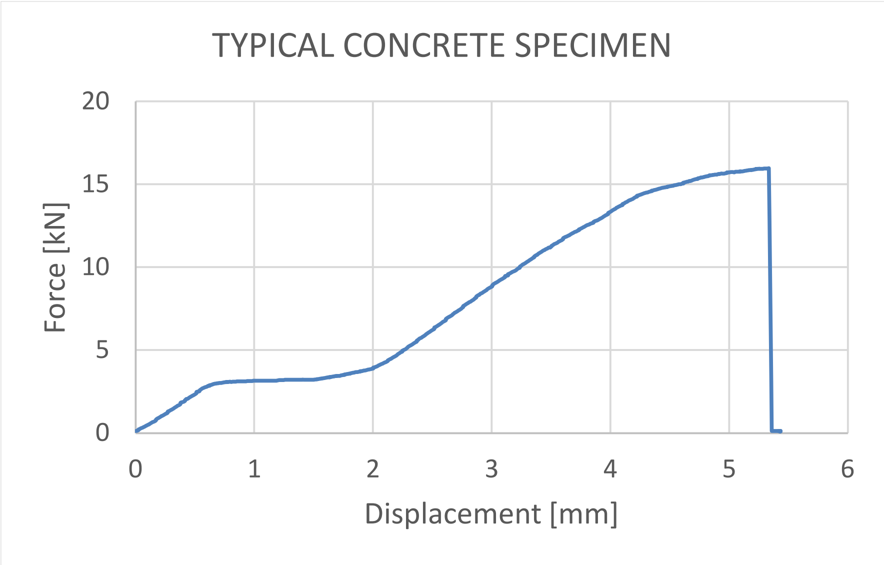
Age/Days	14	28
Weigth/Kg	12,22	19,64
Compressive strength/Mpa	12,04	31,34

Figure 17. The ordinary specimens under the compressive strength test.

II. Flexural test

Figure 18. The typical specimen under flexural strength test.

Figure 19. The magnitude of applied load and displacement of the typical specimen under the flexural strength test.



Appendix 2: Rotary Kiln Ash specimens

The specimens were produced by utilizing 25%, 45%, 55%, 75%, and 100% of Rotary Kiln Ash and tested at ages of 1, 3, 7, 14, and 28 days for compressive strength. Axial tensile/flexural strength was carried out only at age of 28 days concerning 45%, 75%, and 100% Rotary Kiln Ash.

1. **Rotary Kiln Ash 25%**

Table 7. Recipe of 25% Ash concrete mixture.

Component	Amount %
Cement	16
Water	7.4
Fine aggregate 0-2mm	8.4
Coarse aggregate 0-8mm	30.15
Rotary Kiln Ash 0-8mm	10.05
Coarse aggregate 8-16mm	21
Rotary Kiln Ash 8-16mm	7

Table 8. Weight and compressive strength of specimens utilized 25% Ash.

Age/ Days	1	3	7	14	28
Weight/kg	12,37	12,47	12,23	12,16	12,20
Compressive strength /Mpa	9.2	19.58	20.12	24.54	29.80

2. Rotary Kiln Ash 45%

Table 9. Recipe of 45% Ash concrete mixture.

Component	Amount %
Cement	16
Water	7.4
Fine aggregate 0-2mm	8.4
Coarse aggregate 0-8mm	22.11
Rotary Kiln Ash 0-8mm	18.09
Coarse aggregate 8-16mm	15.4
Rotary Kiln Ash 8-16mm	12.6

I. Compressive strength test

Table 10. Weight and compressive strength of specimens utilized 45% Ash.

Age/ Days	1	3	7	14	28
Weight/kg	12,66	12,43	12,16	12,22	11,56
Compressive strength /Mpa	9,94	13,53	16,29	18,95	23,25

II. Flexural test

Figure 20. The specimen utilized 45% ash under the flexural strength test.

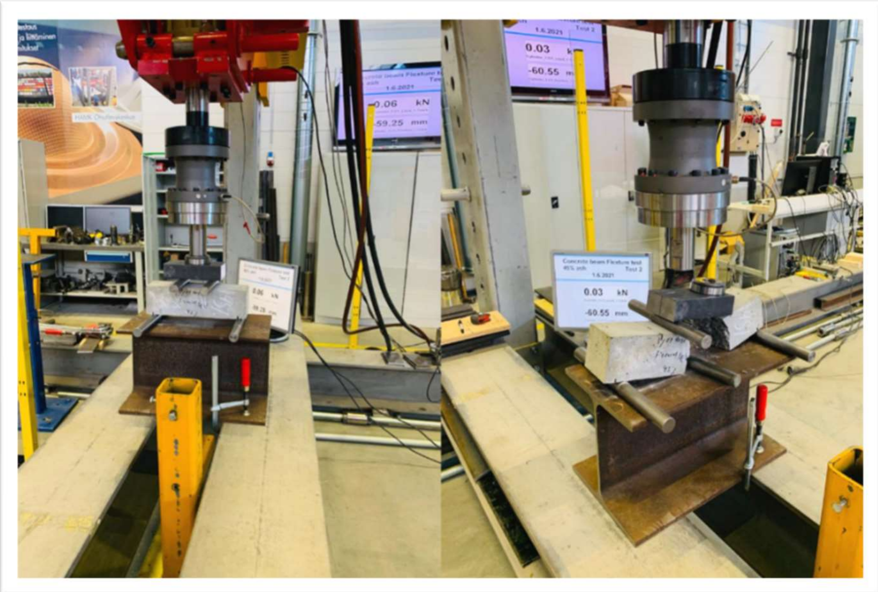
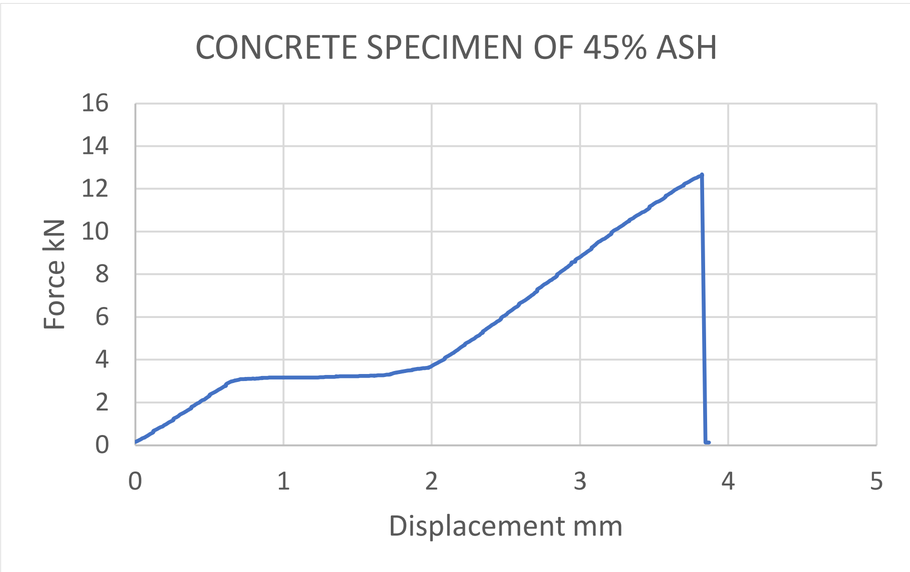


Figure 21. The magnitude of applied load and displacement of 45% ash specimen under the flexural strength test.



3. Rotary Kiln Ash 55%

Table 11. Recipe of 55% Ash concrete.

Component	Amount %
Cement	16
Water	7.4
Fine aggregate 0-2mm	8.3
Coarse aggregate 0-8mm	18.09
Rotary Kiln Ash 0-8mm	22.11
Coarse aggregate 8-16mm	12.6
Rotary Kiln Ash 8-16mm	15.4

Table 12. Weight and compressive strength of specimens utilized 55% Ash.

Age/ Days	1	3	7	14	28
Weight/kg	12,54	12,63	12,55	12,49	12,45
Compressive strength /Mpa	11,44	17,51	22,66	23,32	24,18

4. Rotary Kiln Ash 75%

Table 13. Recipe of 75% Ash concrete.

Component	Amount %
Cement	16
Water	7.4
Fine aggregate 0-2mm	8.3
Corse aggregate 0-8mm	10.05
Rotary Kiln Ash 0-8mm	30.15
Coarse aggregate 8-16mm	7
Rotary Kiln Ash 8-16mm	21

I. **Compression strength**

Table 14. Weight and compressive strength at different ages of 75% utilized Ash specimens.

Age/ Days	1	3	7	14	28
Weight/kg	12,38	12,53	12,67	12,62	12,21
Compressive strength /Mpa	10,45	16,87	18,37	24,28	29,51

II. Flexural test

Figure 22. The 75% utilized ash specimen under flexural strength test.

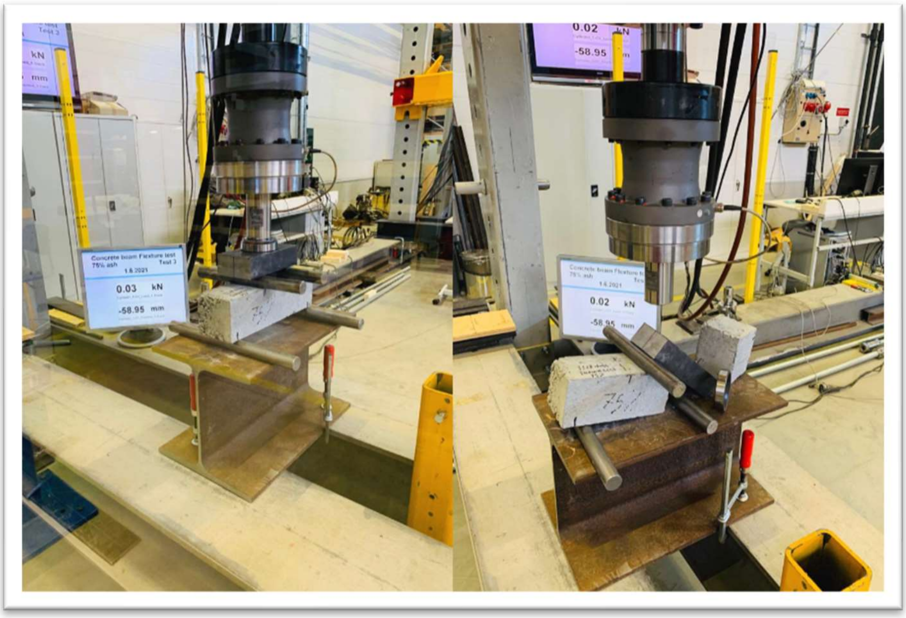
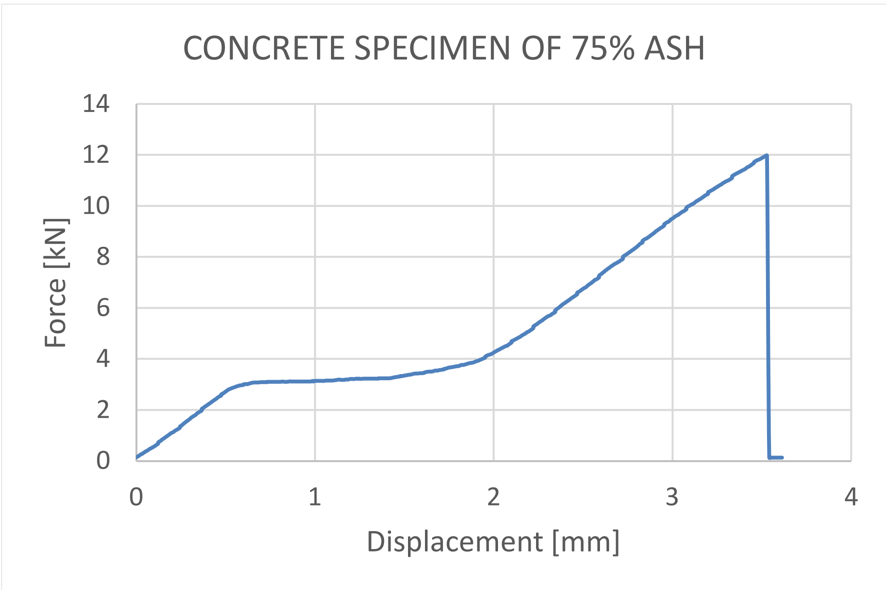


Figure 23. The magnitude of applied load and displacement of 75% ash specimen under the flexural strength test



5. Rotary Kiln Ash 100%

Table 15. Recipe of Rotary kiln ash concrete mixture.

Component	Amount %
Cement	16
Water	7.4
Fine aggregate 0-2mm	8.4
Rotary Kiln Ash 0-8mm	40.2
Rotary Kiln Ash 8-16mm	28

I. Compressive strength test

Table 16. Weight and compressive strength of 100 % utilized Ash specimens at different ages.

Age/ Days	1	3	7	14	28
Weight/kg	12,64	12,53	12,46	12,48	12,37
Compressive strength /Mpa	7,72	10,77	18,59	20,53	24,91

II. Flexural strength

Figure 24. The 100% utilized ash specimen under flexural strength test.

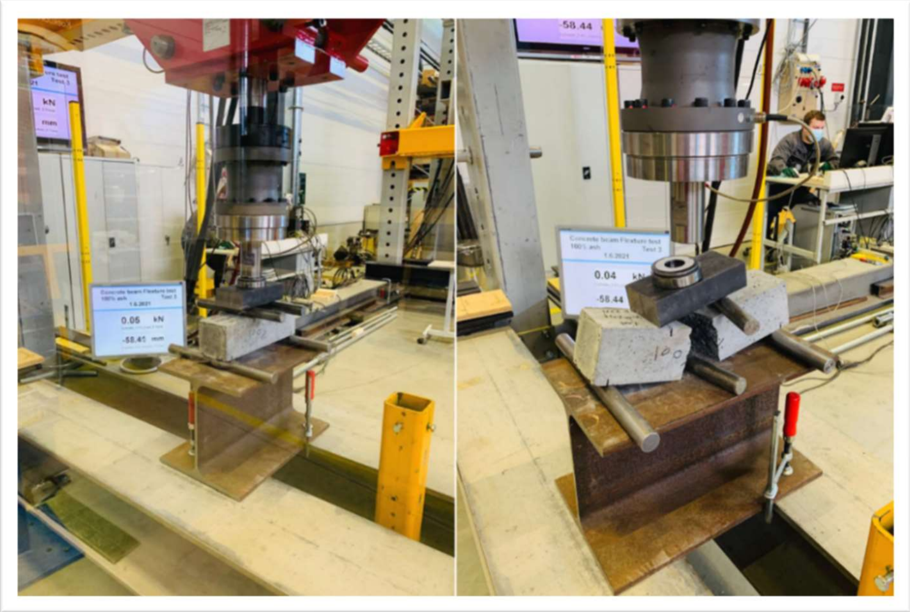


Figure 25. The magnitude of applied load and displacement of 100% ash specimen under the flexural strength test.