FINAL PROJECT

UTILISATION OF USED WHITE PAPER FOR PAPERCRETE (MECHANICAL AND ECONOMIC CHARACTERISTICS)

Submitted to Universitas Islam Indonesia Yogyakarta in Fulfillment for Bachelor of Civil Engineering

By
Waleed Redhwan Mohammed Al-Shehari
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CIVIL ENGINEERING INTERNATIONAL PROGRAM
FACULTY OF CIVIL ENGINEERING & PLANNING
UNIVERSITAS ISLAM INDONESIA
YOGYAKARTA

2024

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Date: 26 April 2024

APPROVAL

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AUTHENTICITY STATEMENT

I declare in fact that the Final Project report that I prepared as a requirement for the completion of the Bachelor program in the Civil Engineering Study Program, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia is my own work. Certain parts of writing the Final Project report that I quoted from the work of others have been written in the source clearly in accordance with the norms, rules, and ethics of writing scientific papers. If in the future it is found that all or part of this Final Project report is not my own work or there is plagiarism in certain parts, I am willing to accept sanctions, including the revocation of my academic degree in accordance with applicable legislation.

Yogyakarta, 26 April 2024

Author,

Waleed Redhwan Mohammed Al-Shehari

DEDICATION

This final project is dedicated to God Almighty Allah SWT as an act of worship by the author as His servant, and to the author's parents who have consistently provided moral and financial support. It is also dedicated to all those who have been part of the author's educational journey during my bachelor's education.

FOREWORD

Bismillahirrahmanirrahim

Assalamualaikum Warahmatullahi Wabarakatuh

Asyhadu Alla Ilahailallah Wa Asyhadu Anna Mohammedarrasulullah Allahuma Shalli'ala Mohammed Wa'ala Alihi Washobihi Wasalam, Alhamdulillahhirrobbil'alamiin, all praise and gratitude I pray for the presence of Allah SWT for the blessing of his mercy and favor, the author was able to complete the Final Project. Shalawat and greetings also did not forget to pour out on the great prophet Mohammed SAW.

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Ultimately, the author expresses gratitude for the help received from various parties, as it has enabled the author's final effort to be of practical value.

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Yogyakarta, 26 April 2024

Author,

Waleed Redhwan Mohammed Al-Shehari

LIST OF NOTATIONS AND ABBREVIATIONS

ASTM	= American Standard Testing and Material
BIS	= Bureau of Indian Standards
GGBS	= Ground Granulated Blast-Furnace Slag
OPC	= Ordinary Portland Cement
PFA	= Pulverized Fuel Ash
WPA	= Wastepaper Ash
WPSA	= Wastepaper Sludge Ash

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ABSTRACT

Papercrete is a construction material created by combining wastepaper with cement and additional substances. It serves as a replacement for traditional concrete and provides advantages like as waste reduction and the mitigation of construction's environmental impact. It serves as a sustainable and eco-friendly substitute for conventional concrete. The objective of this study is to quantify the compressive and flexural strength of papercrete, assess the manufacturing cost of papercrete, and identify the optimal paper proportion in the concrete mix based on both mechanical and economic factors.

An experimental study was conducted to examine the mechanical and economic properties of papercrete with different paper proportions. White wastepaper has been incorporated into the concrete mixture. The ratio of cement to sand remained steady at 1:6. This mix design incorporates six different ratios of wastepaper to cement, ranging from 0% to 20% in increments of 4%. The sample manufacture took place at Pusat Inovasi Material Vulkanis Merapi UII, while the laboratory testing was conducted at Laboratorium Bahan Konstruksi Teknik UII. A survey was done to obtain production cost data from multiple vendors located near Kaliurang Street.

The compressive and flexural strengths of papercrete are generally reduced when white wastepaper is used in papercrete ingredient. The strength decreases with increasing wastepaper content. The cost of wastepaper papercrete is higher than that of normal concrete (0% wastepaper). The cost of papercrete made using white wastepaper increases with its composition. The results shows that there is not a optimum blend of papercrete made with white waste paper in terms of strength and production costs.

Keywords: papercrete, white wastepaper, compressive strength, flexural strength, production cost.

CHAPTER I
INTRODUCTION

1.1 Background

Papercrete is one of the construction material made from waste paper that is mixed with cement and other additives. It is used as a substitute for conventional concrete and offers benefits such as reducing waste and minimizing the environmental impact of construction (Aji et al., 2020). Papercrete is a lightweight material that has strengths comparable to wood and has excellent heat and acoustic insulation properties. Papercrete can be formed into different shapes such as blocks, panels, and sheets with ease. It is a sustainable and environmentally friendly alternative to traditional concrete and wood (Venkatesan et al., 2023).) In order to reduce environmental impact as the effect of human activities on the environment, including pollution, resource depletion, and habitat destruction (Xiong et al., 2023).

In general, there are two mechanical characteristics for concrete test, i.e. compressive strength and flexural strength. Concrete compressive strength test is defined as a measure of the ability of a concrete to withstand compressive forces without breaking or deforming. It is typically determined by applying a compressive load to a specimen and measuring the maximum load it can withstand before failure occurs (Tayeh et al., 2023) the other definition of the compressive strength test is a method used to determine the maximum load that a concrete can withstand before it fails under compression. It involves subjecting a specimen to a gradually increasing compressive load until it fractures or fails (Orouji et al., 2021).

The flexural strength test, also known as the modulus of rupture test, is a mechanical test conducted to measure the maximum bending stress a material can withstand before it breaks or fractures. It involves applying a bending force to a specimen, typically a beam or a rectangular prism, until it reaches its breaking point (Tayeh et al., 2023). The other definition of the flexural strength test is a method used to determine the maximum load that a material can withstand before it fails under bending or flexural stress (Orouji et al., 2021).

Wasted paper could be recycled as additional material in concrete mixtures and illustrated that the compressive strength of the produced concrete decreasing with the increasing of wasted paper ratio more than 10% by weight of cement (Solahudin et al., 2023). Similar results have been showed by Rana (2020) that illustrated that the optimum percentage of adding wasted paper and wasted concrete replacement are 5% and by Tang et al (2020) that wastepaper replacement rate to cement can reach 11.7%. In addition, Tayeh et al (2023) explain that the additional of nylon fibre into concrete mix increased the flexural strength up to 8-10%. As used paper can act as fibre in concrete mix, the additional paper in concrete ingredients will increase the flexural strength as well. There were no detail information what kind of paper the previous research used.

Beside the strength, it is important to consider the production cost of the papercrete. If the cost of construction material is high, some construction actors tend to avoid it and find other materials that suit the construction budget with equal or similar quality. All the previous study above, there are not further economic analysis to measure the influence of concrete production cost of papercrete to the mechanical characteristics. Therefore, consideration of both mechanical and economic characteristics of papercrete needs to be explored further to find the optimum proportion of paper in the concrete mix.

1.2 Problem Formulation

The formulation of the problem has been described as follows.

1. What the mechanical characteristics compressive and flexural strength of papercrete?
2. What the production cost of papercrete?
3. What is the optimum paper proportion in the concrete mix by considering the mechanical and economic characteristics?

1.3 Research Objectives

Based on the formulation of the problem above, the research objectives are as follows.

1. To measure the mechanical characteristics compressive and flexural strength of papercrete
2. To measure the production cost of papercrete
3. To determine the optimum paper proportion in the concrete mix by considering the mechanical and economic characteristics

1.4 Research Benefits

The benefits that will be achieved based on the research objectives are specially for architect and civil engineering professionals, as follows.

1. The strength performance.
   By considering the papercrete strength performance, civil engineer professional can determine what kind of building structure that papercrete can be used for.
2. The economic aspect.
   By considering the papercrete production cost, construction budget can be measured optimally by architect and civil engineer professionals. Moreover, the utilization ad wastepaper is relevant to make a sustainable and green construction material.

1.5 Research Limitation

In order to focus on the research objectives, there are some research limitations as follows.

1. The type of wastepaper is shredded white paper collected from several offices in Sleman and the proportion of wastepaper is 0%-20% based on Ramesh at al (2020).
2. The dimension of papercrete samples for compressive strength and flexural strength is 15 cm x 15 cm x 15 cm and 10 cm x 10 cm x 40 cm respectively.
3. The samples production is in Pusat Inovasi Material Vulkanis Merapi UII.

4. The samples strength test is in Laboratorium Bahan Konstruksi Teknik UII.
5. The methods that are used for mix design is SNI 03-6468-2000 for water, cement, and wastepaper. For flexural strength or modulus of rupture tests were performed in accordance with ISO 178:1993 and a compressive strength machine (Standard Pengoprasian Alat Compressive Test Machine Controls (CAT C75) and Standard Pengoprasian Alat Compressive Test Machine (ELE INTERNATIONAL ADR 3000) was used to determine the compressive strength of the concrete (capacity of 1000 KN) cubes.
6. Replacing wastepaper from cement can find the optimum concrete with ratio 0%, 4%, 8%, 12%,16%, and 20% and prepared of W/C 0.48.

CHAPTER II
LITERATURE REVIEW

2.1 Research Results I

Previous research conducted by Sudarsan et al. (2017) was about **"Papercrete brick as an alternate building material to control environmental pollution".** This study looked at the possible applications of low-weight composite brick as building materials and the possible low-cost production of paper waste. Experimental investigation was carried out to analyse optimization of mix for papercrete bricks depending upon the water absorption, compressive strength and unit weight. Papercrete bricks were prepared out of waste paper, and quarry dust with partial replacement of cement by product fly ash in varying proportions of 25% and 55%. This study using 10% proportion of paper in papercrete.

The properties like mechanical strength, standard quality comparisons with the conventional bricks through standard tests like hardness, soundness, fire resistance and Cost-Benefit Analysis were performed and studied. They claimed that these "papercrete" structures are strong and good at durable and insulating. But they had no research to backup their claims until now. They were cast into seventeen group of papercrete mix proportions. Cement plays an important role in the compressive strength and behavior. Specimens with higher proportion of cement exhibit larger Young's Modulus. The specimens of dimension 230mm x 110mm x 80mm were subjected to 7 days and 28 days air curing and sun drying before tests were performed on them.

The results showed papercrete bricks satisfy the basic characteristics of conventional bricks, the basic qualities of conventional brick are: they should be of uniform colour, should have even surfaces, free from cracks and should have sharp and defined edges. They should be hard; so that no impression is left when scratched with fingernails and should produce clear ringing sound when struck with each other. Average weight should be 30 N to 35 N. An bricks should have low thermal conductivity and should have percentage of water absorption by weight less than

20%, when soaked in cold water for 24 hour. Based on the research it was found that for non-load bearing walls papercrete bricks are best suited.

2.2 Research Results II

Another research by Ramesh et al (2020) had done an experiment on **"Experimental research on papercrete preparation and characteristics"** had done an experiment to obtain mechanical properties like durability, basic physical, and chemical properties, and the structural performance of papercrete. This study using 20% proportion of paper in papercrete.

In this research the experimental research of construction method of walling was done using Papercrete Technologyis done and compared its strength and durability of the structure, stability, safety and mental satisfaction are factors that assume top priority during cost reduction. It is found that about 26.11% of the construction cost can be saved for walling alone. This proves that using low-cost building technologies is a cost-effective construction approach for the industry. Papercrete is a sustainable building material due to reduced amount of cement usage and recycled paper being put to good use. The high volume of concrete offers a holistic solution to the problem of meeting the increasing demands for concrete in the future in a sustainable manner and at a reduced or no additional cost and at the same time reducing the environmental impact of industries that are vital to economic development. As natural sources of aggregates are becoming exhausted, it turns out urgent to development. The majority of abandoned paper waste is accumulated from the countries all over the world causes certain series environmental problems.

This research showed parametric experimental research which investigates the potential use of paper waste for producing a low-cost and light weight concrete as a building material. An experimental investigation has been carried out to optimization of mix for papercrete depending upon the compressive strength and flexural strength.

2.3 Research Results III

Ghosh (2018) recognized papercrete as a sustainable building material. Papercrete was regarded as a sustainable building material due to reduced amount of cement usage and recycled paper being put to good use. It has numerous advantages in construction industry, namely low carbon footprint, recycled material usage, low embodied energy, high strength to weight ratio, high thermal insulation, high sound absorption, aesthetic and cost effective. There are many varieties of papercrete possible when the constituents mixed in different proportions. It gains its inherent strength due to presence of hydrogen bonds in microstructure of paper. This thick mix can then be poured into moulds and cast like concrete, to make it into any desired shape and size. This study using 5% proportion of paper in papercrete.

Different parameters such as strength, durability, density and water absorption is determined to check the feasibility. This research was conducted with an aim to learn the small scale preparation of papercrete blocks, its design and construction skills and also had a focus on the assessment of the properties of this building blocks. The research recognized papercrete as a sustainable building material and emphasized on more research towards its performance parameters. This research reviews about the environment impact caused by the paper pollution. Further it discusses about the numerous advantages and disadvantages of papercrete in the construction industries. Properties like absorption, crushing strength, hardness, presence of soluble salts, etc. are studied. Certain measures to overcome the limitations in the properties are also mentioned.

This research showed papercrete bricks are suitable for non-load bearing walls only i.e. buildings made from this could be only of one storey. It can be used in inner partition walls as they are water absorbent. Moreover papercrete bricks can also be manufactured. The manufacturing, processing and construction techniques are still not developed enough to facilitate its use and this requires extensive amount of research. Papercrete can be developed as a material which is suitable for low cost housing and temporary shelters and offices and can help reduce carbon footprint. It is thus evident that it can be looked upon as a sustainable building material and has a promising future. Papercrete bricks are relatively light and more flexible so, they are potentially ideal material for earthquake prone areas.

2.4 Research Results IV

Another research by Ahmed (2022) had done an experiment on **"Customizing cardboard as a binder for ecofriendly lightweight building materials"**. This study was recycling paper and cardboard wastes are becoming important to maintaining a green world. In 2018 manufacturing building materials and their constructions account for 39% of global emissions (13.5 billion tons of CO2). This danger alarm requires immediate action towards seeking for alternatives like traditional materials that have less impact on the environment. Therefore, the current study suggests using new combinations to develop lightweight green building materials. The current research proposes to conduct experimental studies to examine the optimal method for customizing cardboard as a binder for ecofriendly building materials. 17 different mixes were considered in the experimental program; none of these mixes contained cement or consumed any kind of energy.

The aim was to develop sustainable lightweight construction materials. Experimental strength results showed a higher strength (up to 7.5 MPa) for some developed substances 22% higher than the strength of traditional mud samples and simultaneously reduction in their weights (dry density 1600 to 1600 kg/m^3) in between 13%–16% with superior outdoor durability performance. With these promising results and advantages, the current study can be considered as a primary step towards production of ecofriendly building materials. Therefore, the results of this trial emphasize decisions on further future experiments on the potential uses of mixed cardboard as a binder which increases the strength, improves the ductility, reduces the self-weight and better controls the shrinkage and is mainly ecofriendly.

2.5 Research Results V

Another research by Kumari & Kumar (2022) had done an experiment on **"Comparative study of normal clay bricks, fly ash bricks and papercrete**

bricks". Presently there were various imaginative low-cost construction methods and alternate building materials are being utilized since long back fulfils useful just as particular prerequisites of conventional materials/procedures and provide an avenue for the drop-down the development cost and environmentally friendly. The main aim of this paper to make a comparative study of the main three bricks types namely normal clay brick, fly ash brick and Papercrete brick and their properties like absorption, crushing strength, hardness etc.

Clay brick was being used from the last many decades in building construction. Clay brick is very important and common construction material which is used in all masonry work. A large land area is used for acquired clay for brick making. Normal clay brick is a clay product, made by the help of clay mould (it can be table moulded or ground moulded) and baked in kiln or clamp. Clay is the main part of productive land and to solve this problem. Fly Ash brick has come as a non-conventional brick. Fly Ash brick helps in converting industrial waste material into quality building material as well as it is strong, effective and economical than the clay brick. Papercrete is a kind of fibrous cement or stringy bond, made by waste item like an old newspaper, cardboards etc. as pulp in water, Portland cement and sandy soil. Papercrete has the property of good fire-resistant, sound retention and thermal insulation and numerous advantages in the construction industry such as cost-effective, light and more flexible material and aesthetic.

Compressive quality tests on 15 cm x 15 cm x 15 cm papercrete 3D shapes uncovered a normal compressive strength of 0.57 N/mm^2 after 3 days of cube preparation. Other research likewise proposes comparative outcomes. For more strength, a higher grade of cement can be utilized. Weight and Density- Density of the material expanded with increment in the percentage of cement in the blend and decreased with increment in the quantity of the paper in the mixture. The normal load of 8 cubes cast was seen to be 3.624 kg, in this manner block volume was about 1.07 gm/cm^3. This is thusly lightweight in contrast with standard cement or block brickwork units. Shrinkage- 8-9% shrinkage was estimated in each block. Water absorption- In all case, about 30% was the water absorption of the blocks. Drying time- 40 hours, at any rate, are required for drying of papercrete before it can be moulded. After this, it ought to be sundried for 4 days before use for better quality and strength. Or on the other hand, it tends to be set in a clamp/oven at about 70 °C for 40 hours after casting. Putting it at a higher temperature than this can bring about the isolation of material. Tests for different properties, for example, 7 days and 28 days compressive strength, thermal resistance, sound insulation, behaviour under fire so forth are under advancement.

2.6 Resume of Previous Research Results

In research conducted by Sudarsan et al (2017), entitled about "**Papercrete brick as an alternate building material to control environmental pollution**". This research claimed that these "papercrete" structures are strong and good at durable and insulating. But they had no research to backup their claims until now. They were cast into seventeen group of papercrete mix proportions. Cement plays an important role in the compressive strength and behavior. in this present research abandoned paper waste was used as a partial replacement material in concrete. This research indicates that 80% of the construction cost of a building was contributed by building material and still millions of people in developing countries like India are not able to afford the cost of construction of house. This research is based on potential use of light weight composite brick as a building material and potential use of paper waste for producing at low-cost. Experimental investigation was carried out to analyse optimization of mix for papercrete bricks depending upon the water absorption, compressive strength and unit weight. Papercrete bricks were prepared out of waste paper, and quarry dust with partial replacement of cement by another industrial by-product fly ash in varying proportions of 25%, 40% and 55%. Based on the research it was found that for non-load bearing walls papercrete bricks are best suited.

Ramesh et al (2020) had done an experiment on **"Experimental research on papercrete preparation and characteristics"**. They had done an experiment to obtain mechanical properties like durability, basic physical and chemical properties and the structural performance of papercrete. This research was conducted with an aim to learn the small-scale preparation of papercrete blocks, its design and construction skills and also had a focus on the assessment of the properties of this building blocks. The research recognized papercrete as a sustainable building material and emphasized on more research towards its performance parameters. The manufacturing, processing and construction techniques are still not developed enough to facilitate its use and this requires extensive amount of research. Papercrete can be developed as a material which is suitable for low-cost housing and temporary shelters and offices and can help reduce carbon footprint.

Ghosh (2018) conducted an experiment on **"A review on paper crete: a sustainable building material".** This research reviews about the environment impact caused by the paper pollution. Further it discusses about the numerous advantages and disadvantages of papercrete in the construction industries. Properties like absorption, crushing strength, hardness, presence of soluble salts, etc. are studied. Certain measures to overcome the limitations in the properties are also mentioned. Much research is being carried out globally on the material but it is yet to be acknowledged by Indian standard practices and codes and recognized by major building material organizations in India. This research was conducted with an aim to learn the small scale preparation of papercrete blocks, its design and construction skills and also had a focus on the assessment of the properties of this building blocks. The research recognized papercrete as a sustainable building material and emphasized on more research towards its performance parameters. The research recognized papercrete as a sustainable building material and emphasized on more research towards its performance parameters.

Kumari & Kumar (2022) had done an experiment on **"Comparative study of normal clay bricks, fly ash bricks and papercrete bricks".** The main aim of this paper to make a comparative study of the main three bricks types namely normal clay brick, fly ash brick and Papercrete brick and their properties like absorption, crushing strength, hardness etc. Clay brick being used from the last many decades in building construction. Clay brick is very important and common construction material which is used in all masonry work. Tests for different properties, for example, 7 days and 28 days compressive strength, thermal resistance, sound insulation, behaviour under fire so forth are under advancement.

Another research by Ahmed (2022) had done an experiment on **"Customizing cardboard as a binder for ecofriendly lightweight building materials"**. This study was about recycling paper and cardboard wastes are becoming important to maintaining a green world. Therefore, the current study suggests using new combinations to develop lightweight green building materials. There are 17 different mixes that were considered in the experimental program; none of these mixes contained cement or consumed any kind of energy. Eco-friendly building materials that have sustainable features and optimum insulating properties that could be utilized when recycled would eventually contribute to addressing key environmental concerns(such as reduction in greenhouse gas emissions). In addition, better insulation of the building envelope reduces mechanical energy dependency for cooling and heating purposes, eventually contributing to the betterment of the environment. Therefore, the results of this trial emphasize decisions on further future experiments on the potential uses of mixed cardboard as a binder which increases the strength, improves the ductility, reduces the self-weight and better controls the shrinkage and is mainly ecofriendly.

In this study, an experimental method was conducted regarding the utilisation of used white paper for papercrete. The research was conducted based on previous references to the mechanical and economic characteristics of papercrete according to the research by Sudarsan et al (2017), Ramesh et al (2020), Amed (2022), Ghosh (2018), and Kumari & Kumar (2022). The differences and similarities of this study with previous research are described in Table 2.1.

Table 2. 1 Previous Research

No	Author	Comparison		Result
		Differences	**Similarities**	
1	Sudarsan, J. S., Ramesh, S., Jothilingam, M., Ramasamy, V., & Rajan, R. J. (2017)	**Experiemental Procedure :** Gravity test, sieve analysis, bulk density	Analyse optimization mix of papercrete	The basic qualities of conventional brick are: they should be of uniform colour, should have even surfaces, free from cracks and should have sharp and defined edges. The bricks should have low thermal conductivity and should have percentage of water absorption by weight less than 20%, when soaked in cold water for 24 hours

No	Author	Comparison		Result
		Differences	Similarities	
2	Ramesh, M. P., Sivaranjani, M., Sujaatha, A., & Karpagavalli, M. (2020).	1. **Mix Properties :** Specific gravity, colour, density, mose content, initial setting time, final setting time, soundness 2. **Durability Test**	1) **Mix Design:** Cement : Sand: Paper 2) **Compression Test**	This study was conducted with an aim to learn the small-scale preparation of papercrete blocks, its design and construction skills and also had a focus on the assessment of the properties of this building blocks The manufacturing, processing and construction techniques are still not developed enough to facilitate its use and this requires extensive amount of research.

No	Author	Comparison		Result
		Differences	Similarities	
3	Ghosh (2018)	a. **Mix Design:** Flyash b. **Dimension :** 235 mm x 105 mm x 90 mm c. **Analyse : Water** absorption and weight	1. **Mix Design:** Cement : Sand: Paper 2. Compressive Strength	The study recognized papercrete as a sustainable building material and emphasized on more research towards its performance parameters. The weight of this brick is 1/3rd to 2/5th lesser than conventional clay brick. These bricks are not suitable for water logging and external walls. It can be used in inner partition walls as they are water absorbent

No	Author	Comparison		Result
		Differences	**Similarities**	
4	Ahmed (2022)	1) **Mix Proportion:** Cardboard, Clay, Cork, Syrup 2) **Testing:** Density	Mechanical performance testing	Experimental strength results showed a higher strength (up to 7.5 MPa) than the strength of traditional mud samples and simultaneously reduction in their weights dry density 1600 to 1600 kg m−3
5	Kumari & Kumar (2022)	1) **Mix Design:** Quarry Dust 2) **Comparative analysis:** Normal clay bricks, fly ash bricks	1. **Mix Design:** Cement : Sand: Paper 2. Compressive Strength	The result shows that Fly Ash bricks having higher compressive strength, Papercrete having lowest compressive strength therefore, it cannot be used as a load-bearing wall.

CHAPTER III
THEORETICAL BACKGROUND

3.1 Introduction to Papercrete

Papercrete is a “new” experimental material that is not yet produced from many commercial manufacturing companies. Papercrete was a material originally developed 80 years ago but it is only recently rediscovered. Papercrete is a fibrous cementitious compound comprising waste paper and Portland cement. Papercrete presents high environmental potential due to the fact that it replaces an amount of cement by the use of paper and the total weight, cost and CO_2 emissions during production are reduced (Ambika et al., 2023). It has potentials to become a future building material for lightweight applications thanks to its low cost and high recycle paper content.

Papercrete is mainly made from recycled paper that is combined usually with sand and Portland cement creating a composite material that is malleable and can be casted and molded in various forms and shapes (Kumari et al., 2022). Papercrete can be casted and pressed into bricks, blocks and panels and can be used in the building industry for a variety of applications (Tangbo et al 2020). Papercrete can be used also as a casting material in-situ that can be applied directly to walls as “gunned/shotcrete” to construct monolithic structures. Waste paper can be derived from newspaper, junk mail, magazines, and books. It is noticed that some types of paper work better than others; newspaper is most commonly used because it produces consistent results.

Papercrete can be an environment friendly solution to the need of affordable housing (Shelar et al., 2023). In papercrete construction, the mortar, exterior stucco, and interior plaster can be made with the same paper material so much of wood and other construction materials used in framing can be saved. Papercrete has good sound absorption characteristics. Papercrete made with certain mixes are resistant to fire, fungi, and pests of all kinds. Papercrete blocks made with a sufficient quantity of Portland cement and sand are fire retardant. Papercrete blocks can be easily made fireproof by coating them with a solution of boric acid and borax. By using a concrete sealer the papercrete blocks can be made waterproof.

The basic constituents of papercrete are water and any kind of paper (newspaper, cardboard, glossy magazine stock, advertising brochures, junk mail or any other type of paper). These fibers from paper add strength to cement, just as glass fibers add strength to fiberglass. In the case of papercrete, these fibers can actually make up the bulk of the mix, resulting in a product that is both lightweight and strong.

Due to the light weight of Papercrete building blocks it can be used for interior walls in high-rise buildings in seismically active areas. Using papercrete building blocks in place of conventional or concrete bricks/blocks could reduce the dead load of structure and reduce the steel percentage and the depth of foundations required. Use of wastepaper in concrete could become an economical and profitable substitute to landfills, incinerator, or other use options (Abushammala et al., 2023). This research is intended to assess the durability, performance, and environmental impact of papercrete concrete compared to traditional building materials using Life Cycle Assessment (LCA).

3.2 The Influence of Wastepaper used in Concrete

3.2.1 General Properties

This research shown the use of wastepaper sludge ash (WPSA) for structural concrete in binary and ternary mixes with high strength cement and two industrial by-products, ground granulated blast-furnace slag (GGBS) and pulverized fuel ash (PFA). The potential use of WPSA in this type of concrete and its combination with other supplementary cementation materials has not been established; thus, further research is needed prior to industrial-scale applications. A series of tests investigated the soundness and setting times of the resulting cements, the fresh concrete work ability, cube compressive strength at various curing times, tensile splitting strength, textural strength, static modulus of elasticity, water absorption and carbonation of the resulting concrete (Singh et al., 2022). Good binary WPSA mixes were achieved with high early strength gains, but work ability reduced;

binary mixes with 15% WPSA, were overall the best in terms of strength and durability, whilst maintaining pumpability. An improvement in the carbonation resistance of ternary GGBS and PFA mixes was also indicated upon addition of WPSA although their strengths were lower than those of binary WPSA mixes. Further mix optimisation can lead to other robust and durable high-strength cement systems with WPSA, allowing for higher cement replacements in structural concrete, for improved environmental impact.

This research is aimed at analyzing the problem of paper waste on concrete strength and developing mixing ratio for concrete paper waste. Paper waste has been used for decades as a construction material, particularly in cement matrices. Since then a considerable amount of research has been undertaken to prepare the mechanical properties of the composite such as compressive strength, work ability and fire resistance. By using the waste paper, Papercrete is not only reducing the amount of using cement, but also making environmentally friendly building materials (Bochare et al., 2023). In order to reduce non-renewable material consumption as well as maintaining natural resource concepts of recycling and sustainability were globally introduced.

3.2.2 Workability

Many factors are accountable for adverse effects on the workability of paperwaste; concrete such as amount of paperwaste replacement, paperwaste physical properties and the carbon content of the paperwaste would be the central reasons for the lowering of concrete workability. Workability is one of the important features defining the fresh properties of concrete and can be defined as a measure of the ability of concrete to be mixed, handled, transported and placed without loss in homogeneity and with less air voids. A slump test is a suitable test to determine the workability for all types of concrete mixes; the test was performed according to ASTM C143. Ingale et al (2023) shows addition of 20% calcined paper sludge with cement paste accelerates setting time by 60 minutes but results in reduction of workability.

The spotted compressive, splitting tensile and flexural strength raised up to 10% addition of waste paperwaste and further increase in waste paperwaste minimizes the strengths progressively. So the most appropriate mix proportion was using 5 to 10% replacement of waste paperwaste by weight of cement (Solahuddin, 2022).

Addition of 20% calcined paper sludge with cement paste accelerate setting time by 60 minutes, but results in reduction of workability (Ahmad et al., 2023). The workability of concrete containing paper-mill residual was improved by the addition of super-plasticize to achieve good workability with reinforced strength of papercrete. While density decreased by the addition of paper. Several factors could lead to apposite effects on the workability and density of papercrete. The amount of paperwaste addition, paperwaste physical properties, and the carbon content of the paperwaste would be the main reasons for the reduction of concrete workability and density. The increase in water demand becomes larger with an increase in the paperwaste content to about 20% (Alshahwany *et al.*, 2020).

The workability of concrete is usually assessed in Great Britain roughly by means of the slump test or more precisely by means of the compacting factor test, both of which have been in use for some years and are amply described elsewhere. To determine the workability of the fresh concrete, the slump test was conducted according to ASTM C 143. As specified by this method, concrete was placed in the slump cone in three approximately equal layers and consolidated by rodding each layer 25 times with a smooth, straight steel tamping rod. After the top layer was compacted, the excess concrete was struck off and the mold was removed slowly. Then, the slump was determined by measuring the difference in level between the height of the inverted cone and that of the highest point of the subsided concrete and reported as a slump.

The tests performed which are compressive strength, flexural strength and also determining the workability of fresh prepared papercrete. The workability test such as slump cone test is performed for fresh concrete mix. For compressive strength test was undertaken in accordance with the technical requirements, a universal testing machine is used for performing compressive tests, the papercrete specimens size 150mm x 150mm x 150mm are to be casted and tested after curing period of 7 days and 28 days.

A compressive strength machine (Model: EIE-TM-042) was used to determine the compressive strength of the concrete (capacity of 1000 KN). These results indicate that the slump decreased with the increase in WPA content. This effect can be attributed to the fact that WPA has a high-water absorption capacity compared to cement and thus the content of water in the mix is reduced (hence less workable concrete is produced). The second reason is due to the lower density of WPA giving it a higher porosity resulting in higher water demand. Even though the slump value is decreased as the percentage of WPA is increased, until the percentage is 20% the slump value is within the specified limit, which is 30–50. The highest slump was seen for the control concrete mix. The effect of replacing Portland cement with paper pulp on the workability of concrete has been examined by several researchers and they observed that the workability decreased when a higher amount of paper ash content was included (Ahmad et al., 2023). Ingale et al (2023) reported that the slump increased with up to 5% replacement of cement. Above 5%, the slump decreased as the paper pulp content in the concrete mixtures was increased.

The ratio of sand to cement was chosen because the results obtained by Luo et al (2023) showed that the sand-binder ratio of 1.0 (out of the considered sand-binder ratios they considered) had the best mechanical properties, with economy also in view. Cement and sand of equal proportion were also mixed and used to produce sandcrete cubes, whose structural properties were also compared with those of the papercrete cubes. Addition of 20% calcined paper sludge with cement paste accelerate setting time by 60 minutes, but results in reduction of workability (Ahmad et al., 2023). So the most appropriate mix proportion was using 5 to 10% replacement of waste paperwaste by weight of cement (Solahuddin, 2022).

3.2.3 Compressive Strength

Compressive strength refers to the ability of a certain material or structural element to withstand loads that reduce the size of that material, or structural element when applied. A force is applied to the top and bottom of a test sample, until the sample fractures. The formula to calculate compressive strength is in Equation 3.1.

$$\sigma = \frac{P}{A} \tag{3.1}$$

where:

σ =the compressive strength (MPa)

P=maximum load (or load until failure) to the material (N)

A=A cross-section of the area of the material resisting the load (mm^2)

Oruji et al., (2021) worked to investigate the mechanical and physical properties of papercrete by conducting few laboratory tests to find out the compression strength capacity, bond characteristics through pull out test, behavior under long term sustain loading (creep) and thermal conductivity test found that stress-strain curve increases monotonically, and wastepaper is responsible for the decreased compressive strength.

The results of compressive strength, and splitting tensile strength for (10%, 15% and 20%) mixes decreased with the increase of the amount of wastepaper (Alyami et al., 2023). While in the mixture with (5%), the strength was higher than the reference since waste paper contains considerable amount of alumino-siliceous material that is combined with calcium, leading to the improvement in its strength. The advancement of this strength is predominantly inferable to the hydraulic and pozzolanic activity of waste paper that is activated by the alkalis and to some extent, $Ca(OH)_2$, which is released from the hydration process. While results of flexural strength were less than reference mixes for all test ages. The optimum percent of paper is 20% and can be utilized to produce bricks with light weight and good fire resistance.

3.2.4 Flexural Strength

Flexural strength is a material property, which is defined as "the maximum stress in a material just before it yields in a bending test". Flexural strength is also known as bending strength. Most materials fail due to tensile stress before they fail under compressive stress. This is caused by small defects of various sizes at the surface, which will grow under tensile stress. Therefore the maximum tensile stress value under bending before the beam or rod fails is considered its flexural strength.

A 40 cm-long rectangular sample of the material is supported at its ends, so there is no support in the middle, but the ends are sturdy. A load or force is then applied to the middle section until the material breaks. For a rectangular sample under a load in a four-point bending setup (Figure 4.1). The formula for calculating the flexural strength of concrete is as follows.

$$\sigma = \frac{M\,.\,c}{I} \tag{3.2}$$

where:

M = the moment in the beam

c = the maximum distance from the neutral axis to the outermost fiber in the bending plane

I = the second moment of area

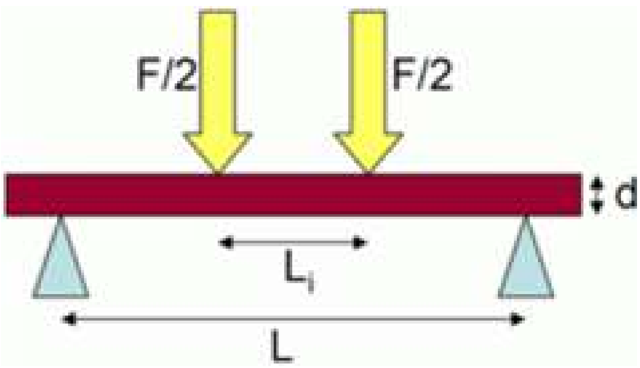

Figure 3. 1 Supported Beam

For a simple supported beam as shown in Figure 3.1, assuming the load is F (the load (force) at the fracture point) and distributed as F/2 and F/2 between the supports, and each support reaction is F/2. Then, maximum moment is at the center and is equal to the below, as presented in Equation 4.3:

$$M = \frac{F}{2} * \frac{L}{2} - [\frac{F}{2} * \frac{Li}{2}]$$

$$M = \frac{F.L}{4} - \frac{F.Li}{4}$$

$$M = \frac{F * L - F * Li}{4}$$

$$M = \frac{F * [L - Li]}{4} \qquad (3.3)$$

For a rectangular cross section,

$c = \frac{1}{2}d$ (central axis to the outermost fiber of the rectangle)

$I = \frac{1}{12}bd^3$ (Second moment of area for a rectangle)

Where:

F= maximum load (or load until failure) to the material

L= the length of the support (outer) span

b= width

d= thickness

Li= the length of the loading (inner) span

Combining these terms together in the classical bending stress equation provide flexural strength as described in Equation 3.4.

$$\sigma = \frac{M * c}{I}$$

$$\sigma = M * \frac{c}{I}$$

$$\sigma = \left[\frac{F * [L - Li]}{4}\right] * \frac{c}{I}$$

$$\sigma = \left[\frac{F*[L-Li]}{4}\right] * \frac{\frac{d}{2}}{\frac{b*d^3}{12}}$$

$$\sigma = \left[\frac{F*[L-Li]}{4}\right] * \frac{6}{b*d^2}$$

$$\sigma = \frac{3*F*[L-Li]}{2*b*d^2} \tag{3.4}$$

3.2.5 Production Cost Analysis

Production cost is calculated based on each ingredient cost i.e. labor cost, material cost, and equipment cost. Standard of Public Work Minister No 28/PRT/M/2016 about Unit Cost Analysis for Public Work is used for reference. It is assumed that the quality of the papercrete in this research is about 7.4 MPa. As stated in the standar, the aggregate of sand (869 kg) and gravel (999 kg) is assumed that the sand weight is 1868 kg based on the total weight of sand and gravel. The example of production cost of papercrete with 0% of sludge waste paper follow the Standard on AHSP A.4.1.1.1 as presented in Table 4.2 as follows. A survey is used to get the unit pricing value from multiple vendors around Kaliurang Street, in the Sleman District Area.

Table 3.1 Example of analysis of production cost (unit price) of papercrete

Analysis Code : AHSP A.4.1.1.
Item : Make a Papercrete, f'c = 7.4 Mpa (K = 100)
: Unit Price of Papercrete (0% sludge waste paper)
Unit : m^3

No.	Components	Code	Unit	Coefficient	Unit Price (Rp.)	Amount (Rp.)
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,333	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		kg	247	1,250	308,750
	Sand		kg	1868	209.52	391,383.36
	Sludge wastepaper 0% x 247 kg		kg	0	30.33	0
	Water		Liter	215	65.00	13,975
				Material Cost (B)		**714,108.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					948,664.36
E	Overhead & Profit			10% x D		94,866.436
F	**Unit Price of Papercrete (D + E)**					**1,043,530.796**

3.3 Application of Papercrete

Based on the previous results, paper crete have the ability to provide an eco friendly, light weight concrete block with the use of less number of natural resources. Though the results obtained during compression test showed that paper Crete bricks are acceptable for non load bearing walls only. As per research the bricks should not absorb water more than 20%. The water absorption capacity of paper Crete brick was found to be more than 20%, which makes it not suitable for water logging and external walls. However, by providing a waterproof coating (Geo bond or silicon based waterproofing) it can also be used as external wall.

Papercrete has a high fire resistance, good sound absorbent, good thermal resistance with an R value between 2 to 3 per inch. In walls 12 to 16 inches thick, the long energy saving of papercrete will be a great advantage for the house owner and environmental as follows:

1. They are largely used in the building of houses.
2. They can be mould into any different shapes to decorate houses, flowerpots, etc.
3. Can be used as sound proofing material.
4. It is less catastrophic then materials like concrete so they can be used in high rise buildings in seismic zones.
5. They can be also used in simple furniture in interiors as it provides aesthetic and opportunity for diverse designs. Literature illustrates its uses for partition walls, and façade material where benefit of dead load reduction of the structure is obtained.
6. It can be used in interiors as it provides aesthetics and opportunity for diverse designs.
7. High rise buildings in seismic zone can use papercrete as it is less catastrophic then other materials like concrete but due to limitations in some other properties such as behavior towards fire, durability concerns, biodegradability etc. it requires a significant amount of research for justifying its applications.

CHAPTER IV
EXPERIMENTAL METHOD

4.1 Introduction

The purpose of this experimental study was carried out to investigate the mechanical and economic characteristics of papercrete with various proportion of paper. The calculation for compressive and flexural strength of papercrete by doing some trial mixes of papercrete. The samples production was in Pusat Inovasi Material Vulkanis Merapi UII and the samples strength test was in Laboratorium Bahan Konstruksi Teknik UII.

4.2 Materials

There are 4 materials that were used in this papercrete mix, i.e. wastepaper, cement, sand, and water, as follows. Methods of manufacturing of papercrete are mixing, pouring, and curing.

A. Wastepaper

This investigation utilized discarded paper from office institutions in Sleman. To prevent the clumping of wastepaper and to achieve a uniform distribution during blending, waste paper was shredded using a paper shredding machine and then immersed in a water tank for three days. Afterwards, the sludge wastepaper was manually squeezed to remove the excess water content, and then it was ground using a mixer grinder to obtain the desired sludge. Following that, the paper sludge was stored in plastic containers. Figure 4.1 depicts the procedure for preparing sludge wastepaper.

Figure 4.1 Wastepaper preparation

B. Cement

Ordinary Portland Cement (OPC) was used for this research with the brand “Semen Tiga Roda” as depicted in Figure 4.2.

Figure 4.2 Portland cement

C. Sand

The sand is collected from sand quarry in Cangkringan, Sleman. To achieve uniform size of sand particles, the sand is sieved with 2.36 mm sieve. Figure 4.3 presents sieve process of sand.

Figure 4.3 Sand sieve

D. Water

The water is used for chemical hydration reaction with cement. This is used well water from Pusat Inovasi Material Vulkanis Merapi UII.

4.3 Mix Design

Proportion of cement to sand was constant as 1:6. This mix design uses six variations of the wastepaper proportion for 0%; 4%; 8%; 12%; 16%; 20% of cement weigth based on the previous researches, as presented in Table 4.1. The amount of the samples is limited to 10 pieces for compressive test and 6 pieces for flexural test due to the mold availability in the laboratory.

Table 4.1 Mix design

No	Code	Proportion Cement:Sand:Paper	Sample amount	
			Compressive test 15 cm x 15 cm x 15 cm	Flexural test 10cm x 10 cm x 40 cm
1	0%	1:6:0.0	10 pieces	6 pieces
2	4%	1:6:0.04	10 pieces	6 pieces
3	8%	1:6:0.08	10 pieces	6 pieces
4	12%	1:6:0.12	10 pieces	6 pieces
5	16%	1:6:0.16	10 pieces	6 pieces
6	20%	1:6:0.20	10 pieces	6 pieces

Table 4.2 Volume Mixture

Category	Height (cm)	Length (cm)	Weidth (cm)	Volume (cm^3)	Total Volume (cm^3)
Compressive Test	15	15	15	3375	33750
Flexural Test	10	40	10	4000	24000
Total					**57750 cm^3**

Table 4.3 Weight and Density Mixture

Density of Cement	0.00857 Kg		
Density of sand	0.0514 Kg		
Proportion	**Weight (Kg)**		
	Sand	**Cement**	**Paper**
1:6:0%	74.057	12.342	0
1:6:4%	74.057	12.342	0.493
1:6:8%	74.057	12.342	0.987
1:6:12%	74.057	12.342	1.481
1:6:16%	74.057	12.342	1.974
1:6:20%	74.057	12.342	2.46
Total	**444.342**	**74.057**	**7.405**

4.4 Sample Production and Strength Test

Papecrete ingredients were cement, sand, sludge wastepaper by the proportions of weight. First of all, the quantities of all the materials are calculated as per the proportion we had taken. This is mixed with concrete mixer in dry condition, on watertight, non-absorbent dry platform till we get uniform colour. Add the water 25% to 30% of total weight of materials as calculated. This is to ensure even distribution of the constituents within the mixtures and homogeneous mixture in uniform colour. The mixture was then poured into the mould for compression and flexural test. Figure 4.4 presents mixing and pouring the mixture into the moulds.

Figure 4.4 Mixing and pouring the mixture into the moulds

Fresh concrete in mould was then cured fot 28 days with the curing period was limited to 28 days in alignment with the recommendation by Sun et al (2023).

Figure 4.5 Sample test

Drying time- 40 hours, at any rate, are required for drying of papercrete before it can be moulded. After this, it ought to be sundried for 4 days before use for better quality and strength. Putting it at a higher temperature than this can bring about the isolation of material. Compressive strength and flexural strength of each of papercrete cubes at curing ages of 28 days was determined. The average of ten compressive strength results for each curing period, category and mix proportion, was determined. The compressive strength of the cubes was determined in compliance with BSI (1983), using operation procedure universal testing machine (shimadzu UMH-30).

4.4 Research Flowchart

The flow of the research activities is presented in Figure 4.7.

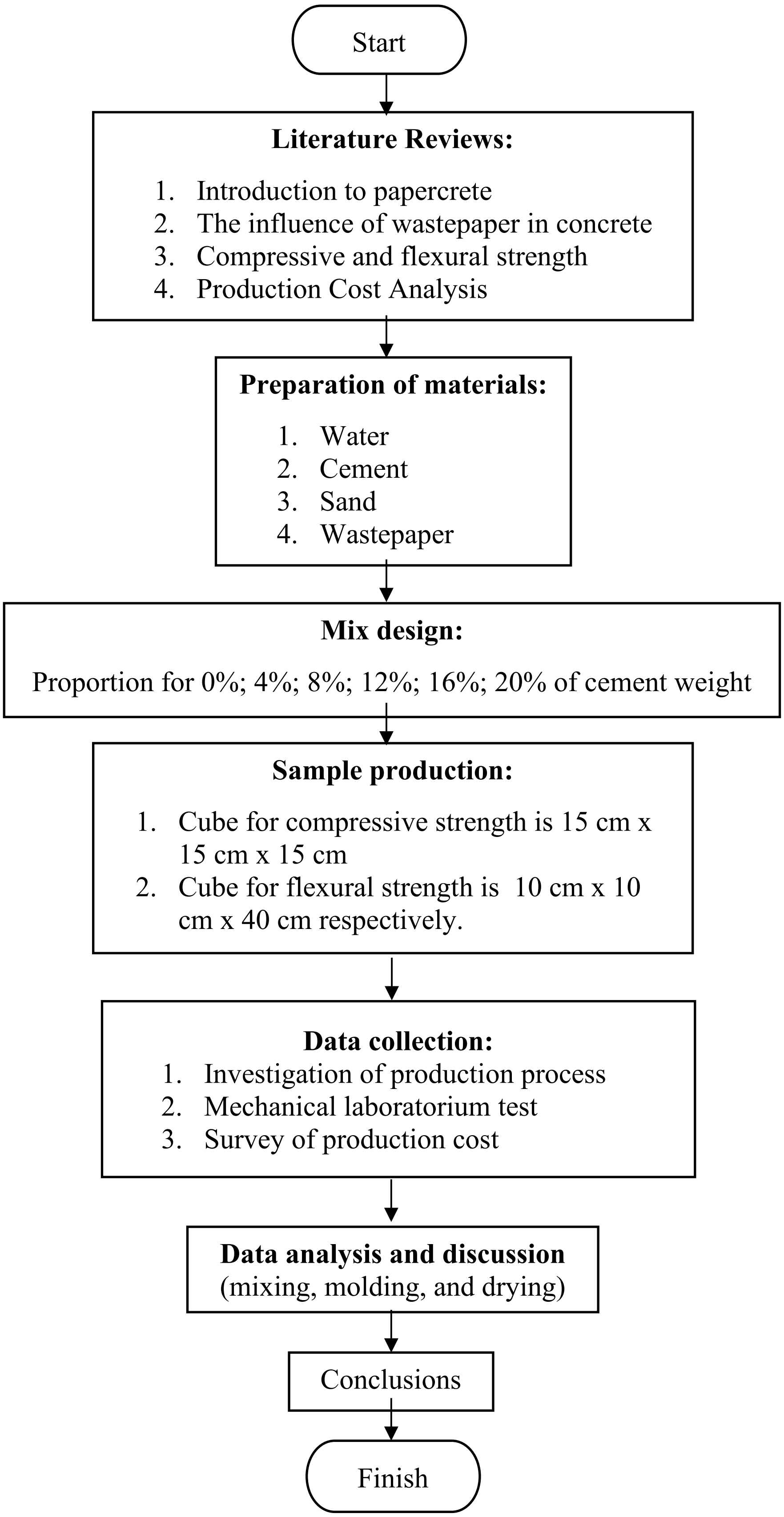

Figure 4.7 Research flowchart

In this study, procedures were carried out that became a reference in answering the problems described at several stages as follows.

1. Literature Reviews

   At this stage, researchers re-observe problems in the field by conducting some research in journals on problems with similar topics. The information related to the research is about papercrete, mix design for concrete, compressive strength, flexural strength, and production cost.

2. Preparation of Materials

   At this stage, researchers prepare the materials that are used in this research such as wastepaper, cement, sand, and water.

3. Mix Design

   Proportion of cement to sand was constant as 1:6. This mix design uses six variations of the wastepaper proportion for 0%; 4%; 8%; 12%; 16%; 20% of cement weight based on the previous researches.

4. Sample Production

   The samples production was in Pusat Inovasi Material Vulkanis Merapi UII and the samples strength test was in Laboratorium Bahan Konstruksi Teknik UII. The dimension of papercrete samples for compressive strength and flexural strength is 15 cm x 15 cm x 15 cm and 10 cm x 10 cm x 40 cm respectively.

5. Data Collection

   At this stage, data collection includes investigation of production process, mechanical laboratories test, and survey for the production cost.

6. Data Analysis and Discussion

   The research will be carried out in Pusat Inovasi Material Vulkanis Merapi UII for sample production and the Laboratorium Bahan Konstruksi Teknik UII for compressice and flexural test. Methods of manufacturing of papercrete are mixing, molding, and drying. The cube produced using each of the papercrete mix ratios were cured for 28 days (age is 28 days).

7. Conclusion

   At this stage, a conclusion will be given that answers the purpose of the research and suggestion that can be given for further research.

CHAPTER V
RESULTS AND DISCUSSIONS

5.1 Production Process of the Samples

The papercrete production process of the samples starts with several activity which include prepare the raw material, sieve the sand, weight the material, mixing, pour the mixed material, and cure the fresh samples and. The documentation in the production process can be seen in Figure 5.1 – 5.3 with a detailed explanation of each manufacturing process as follows.

1. Prepare the raw material

   In making paper crete, the first thing that needs to be prepared is the main materials which called as raw material. The main materials are cement, sand, sludge wastepaper, and water. Researchers obtained raw materials from building shops in Yogyakarta area.

2. Sieve the sand.

   Before mixing cement, sand, sludge wastepaper, and water, it is necessary to sort first. Sand material is done sieving, sieving is carried out to separate a sample according to its particle sizes by submitting.

3. Weight the material

   Furthermore, researchers weighted the raw material according to the coefficient in Table 4.1 Mix Design of the proportion of 0%; 4%; 8%; 12%; 16%; 20% on each cement, sand, sludge wastepaper, and water.

4. Mixing

   All raw materials are mixed using a mixer until all ingredients are well mixed according to Table 4.1 Mix Design of the proportion 1:6:0.0; 1:6:0.0.4; 1:6:0.0.8; 1:6:0.0.12; 1:6:0.0.16; 1:6:0.0.20.

5. Pour the mixed material

   The mixing results are poured into brick molds with a size of 15 cm x 15 cm x 15 cm as much as 10 cubes.

6. Cure the fresh samples and.

Furthermore, cubes are cured for 28 days to get maximum cubes results.

Figure 5.1 Raw material of papercrete: cement, sand, wastepaper, and water

Figure 5.2 Mixing and pouring process of papercrete

Figure 5.3 Samples during curing process for 28 days

5.2 Mechanical Characteristics

An experimental method has been carried out to investigate the mechanical properties of papercrete with 6 variantions of sludge wastepaper: 0%; 4%; 8%; 12%; 16%; and 20% of cement. There are two tests performed which are compressive strength and flexural strength.

5.2.1 Compressive Strength Test

A compressive strength machine (Standard Pengoprasian Alat Compressive Test Machine Controls (CAT C75) and Standard Pengoprasian Alat Compressive Test Machine (ELE INTERNATIONAL ADR 3000) was used to determine the compressive strength of the concrete (capacity of 1000 KN) cubes cured for 28 days. Compressive strength is defined as the sample's ability to withstand an axially applied load, whether on the edge or the bed face of the cube. It is also the average compressive strength of a test sample of 10 cubes. Compressive strength is expressed mathematically as the ratio of maximum crushing load (F) to the minimum surface area (mm^2).

The papercrete specimens was tested for their capacity at compression stage as presented in Figure 5.4. Specimens are tested after 28 days to have comparative data on how the behavior of papercrete develops as it matured. The compressive strength test was taken from six samples which shown on Appendix 1. Here is the papercrete sample after the compression test shown on Table 5.1.

Figure 5.4 Compression test process

Table 5.1 Compressive strength

No	% of sludge waste paper	Compressive Strength (Mpa)
1	0%	12.79
2	4%	12.48
3	8%	10.91
4	12%	8.73
5	16%	8.14
6	20%	5.63

The measured compressive strengths value with various content of sludge wastepaper for 28th days is given in Table 5.1 The compressive strength for the initial test was taken from three samples and then averaged. It shows that the compressive strength for each material proportions are 12.79 N/mm^2; 12.48 N/mm^2; 10.91 KN/mm^2; 8.73 N/mm^2; 8.14 N/mm^2; and 5.63 N/mm^2. According to SNI 03-1974-1990, the minimum compressive strength of bricks is 3.50 N/mm^2. Considering the obtained results the maximum compressive strength is 12.79 N/mm^2 which is 9.29% greater than the minimum compressive strength. The Figure 5.5 shows how the papercrete behaved when compressed under load and the graph shows the average compressive strength of the given samples.

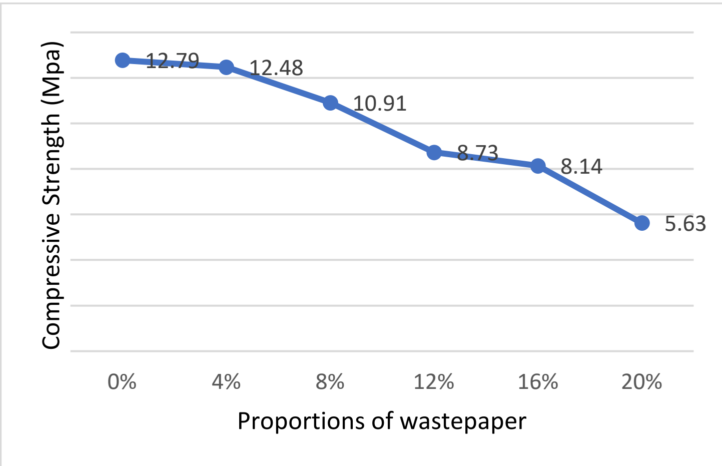

Figure 5.5 Average compressive strength

Based on Figure 5.4 shows that there is a difference in the compressive strength value of each mix proportions. At 0% sludge wastepaper has the highest compressive strength value followed by 4% sludge wastepaper. While the lowest compressive strength value is at 20% sludge wastepaper. Compressive strength decreased by 2.51% in the use of sludge wastepaper 16% and 20%. However, the degree of improvement in strength appeared to be highly dependent on the cement replacement level. It was observed that the concretes with 16% and 20% sludge wastepaper had shown a reduction of compressive strength. This is due to the higher amount of silica found in sludge wastepaper than cement.

Based on this, the larger sludge wastepaper value, has the smaller compressive strength value. In the proportion of 20% of paper pulp the compressive strength of the cube can be observed higher and if the paper pulp is added in higher quantities then the compression strength is decreasing. This is in line with research conducted by Meko et al (2021) that at the age of 28 days the higher the sludge wastepaper value, the lower the compressive strength value. And this was followed by another similar study by Awoyera et al (2021). Oruji et al., (2021) worked to investigate the mechanical and physical properties of papercrete by conducting few laboratory tests to find out the compression strength capacity, bond characteristics through pull out test, behavior under long term sustain loading (creep) and thermal conductivity test found that stress-strain curve increases monotonically, and wastepaper is responsible for the decreased compressive strength.

The compressive strength increases initially on addition of the paper pulp, but it was decreased significantly on further addition of the paper waste. The decrease in compressive strength with the increase in percentage of paper pulp is due to the presence of water absorption content in the composition wastepaper which tends to decrease in its strength.

5.2.2 Flexural Strength Test

The flexural strength of the papercrete is needed for the structural analysis as well. For flexural strength or modulus of rupture tests were performed in accordance with ISO 178:1993 using specimens with a width of 150mm, height of

150mm and a length of 150mm. The Papercrete specimens was tested for their capacity at flexural stage. Specimens are tested after 28 days to have comparative data on how the behavior of Papercrete develops as it matured.

The maximum force applied to the beam was used to determine the flexural strength as presented in Figure 5.6 below. This force was used to calculate the modulus of rupture. The width and depth of the beam at the fracture area was also needed for the calculation. The flexural strength test was taken from six samples which shown on Appendix 2. Here is the Papercrete sample after the compression test shown on Table 5.2.

Figure 5.6 Flexural test process

Table 5.2 Flexural strength

No	% of sludge waste paper	Flexural Strength (Mpa)
1	0%	3.72
2	4%	2.85
3	8%	2.55
4	12%	2.42
5	16%	2.06
6	20%	1.83

The measured flexural strengths value with various content of sludge wastepaper for 28th days is given in Table 5.2. The flexural strength for the initial test was taken from three samples and then averaged. It shows that the flexural strength for each material proportions are 3.72 Mpa, 2.85 Mpa, 2.55 Mpa, 2.42 Mpa, 2.06 Mpa, 1.83 Mpa.

The Figure 5.7 shows how the Papercrete behaved when compressed under load and the graph shows the average flexural strength of the given samples.

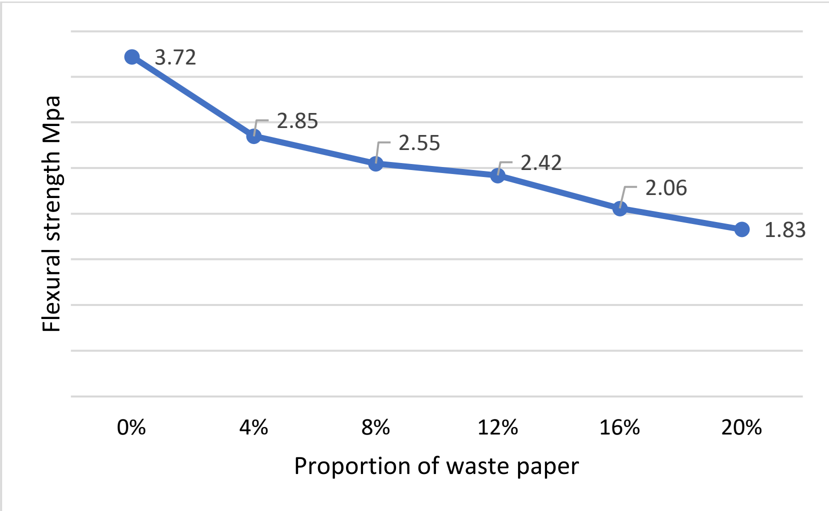

Figure 5.7 Average flexural strength

Based on Figure 5.7 shows that there is a difference in the flexural strength value of each mix proportions. At 0% sludge wastepaper has the highest flexural strength value followed by 4% sludge wastepaper. While the lowest flexural strength value is at 20% sludge wastepaper. Flexural strength decreased by 3,31% in the use of sludge wastepaper 16% and 20%. However, the degree of improvement in strength appeared to be highly dependent on the cement replacement level. It was observed that the concretes with 16% and 20% sludge wastepaper had shown a reduction of flexural strength. Further addition of paper pulp the flexural strength values were decreased.

The decrease in flexural strength with the increase in percentage of paper pulp is due to the presence of low silica content in the composition which tends to decrease in its strength. The study found that the demand for water mixing increased with the increasing WPA addition, which was due to the cellulosic fiber materials leading to high water permeability characteristic.

5.3 Production Cost Analysis

After conducting the survey, the production cost (unit price) in Sleman area for the papercrete was presented in Tables 5.3 – 5.9 below.

Table 5.3 Production cost for sludge wastepaper 0%

Analysis Code : AHSP A.4.1.1.
Item : Make a Papercrete, f'c = 7.4 Mpa (K = 100)
: Unit Price of Papercrete (0% sludge waste paper)
Unit : m^3

No.	Components	Code	Unit	Coefficient	Unit Price (Rp.)	Amount (Rp.)
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,000	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		Kg	247	1,250	308,750
	Sand		Kg	1868	209.52	391,383.36
	Sludge wastepaper 0% x 247		Kg	0	30.00	0
	Water		Liter	215	65.00	13,975
				Material Cost (B)		**714,108.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					948,664.36
E	Overhead & Profit			10% x D		94,866.436
F	**Unit Price of Papercrete (D + E)**					**1,043,530.796**

Table 5.4 Production cost for sludge wastepaper 4%

Analysis Code : AHSP A.4.1.1.
Item : Make a Papercrete, f'c = 7.4 Mpa (K = 100)
: Unit Price of Papercrete (4% sludge waste paper)
Unit : m^3

No.	Components	Code	Unit	Coefficient	Unit Price (Rp.)	Amount (Rp.)
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,000	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		Kg	247	1,250	308,750
	Sand		Kg	1868	209.52	391,383.36
	Sludge wastepaper 4% x 247		Kg	9.88	30,000	296,400
	Water		Liter	215	65.00	13,975
				Material Cost (B)		**1,010,508.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					1,245,064.36
E	Overhead & Profit			10% x D		124,506.436
F	**Unit Price of Papercrete (D + E)**					**1,369,570.796**

Table 5.5 Production cost for sludge wastepaper 8%

Analysis Code : AHSP A.4.1.1.
Item : Make a Papercrete, f'c = 7.4 Mpa (K = 100)
: Unit Price of Papercrete (8% sludge waste paper)
Unit : m³

No.	Components	Code	Unit	Coefficient	Unit Price (Rp.)	Amount (Rp.)
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,000	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		Kg	247	1,250	308,750
	Sand		Kg	1868	209.52	391,383.36
	Sludge wastepaper 8% x 247		Kg	19.76	30,000	592,800
	Water		Liter	215	65,00	13,975
				Material Cost (B)		**1,306,908.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					1,541,464.36
E	Overhead & Profit			10% x D		154,146.436
F	**Unit Price of Papercrete (D + E)**					**1,695,610.796**

Table 5.6 Production cost for sludge wastepaper 12%

Analysis Code : AHSP A.4.1.1.
Item : Make a Papercrete, f'c = 7.4 Mpa (K = 100)
: Unit Price of Papercrete (12% sludge waste paper)
Unit : m^3

No.	Components	Code	Unit	Coefficient	Unit Price (Rp.)	Amount (Rp.)
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,000	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		Kg	247	1,250	308,750
	Sand		Kg	1868	209.52	391,383.36
	Sludge wastepaper 12% x 247		Kg	29.64	30,000	889,200
	Water		Liter	215	65.000	13,975
				Material Cost (B)		**1,603,308.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					1,837,864.36
E	Overhead & Profit			10% x D		183,786.436
F	**Unit Price of Papercrete (D + E)**					**2,021,650.796**

Table 5.7 Production cost for sludge wastepaper 16%

Analysis Code : AHSP A.4.1.1.
Item : Make a Papercrete, f'c = 7.4 Mpa (K = 100)
: Unit Price of Papercrete (16% sludge waste paper)
Unit : m³

No.	Components	Code	Unit	Coefficient	Unit Price (Rp.)	Amount (Rp.)
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,000	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		Kg	247	1,250	308,750
	Sand		Kg	1868	209.52	391,383.36
	Sludge wastepaper 16% x 247		Kg	39.52	30,000	1,185,600
	Water		Liter	215	65.00	13,975
				Material Cost (B)		**1,899,708.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					2,134,264.36
E	Overhead & Profit			10% x D		213,426.436
F	**Unit Price of Papercrete (D + E)**					**2,347,690.796**

Table 5.8 Production cost for sludge wastepaper 20%

Analysis	**Code : AHSP A.4.1.1.**					
Item	**: Make a Papercrete, f'c = 7.4 Mpa (K = 100)**					
	: Unit Price of Papercrete (20% sludge waste paper)					
Unit	**: m³**					
No.	**Components**	**Code**	**Unit**	**Coefficient**	**Unit Price (Rp.)**	**Amount (Rp.)**
A	**LABOURS**					
	Worker	L.01	OH	1.650	110,000	181,500
	Mason	L.02	OH	0.275	123,000	33,916
	Head of Masons	L.03	OH	0.028	150,000	4,200
	Supervisor	L.04	OH	0.083	180,000	14,940
				Labour Cost (A)		**234,556**
B	**MATERIAL**					
	Cement		Kg	247	1,250	308,750
	Sand		Kg	1868	209.52	391,383.36
	Sludge wastepaper 20% x 247		Kg	49.40	30,000	1,482,000
	Water		Liter	215	65.000	13,975
				Material Cost (B)		**2,196,108.36**
C	**EQUIPMENT**					
				Equipment Cost (C)		**-**
D	Total (A + B + C)					2,430,664.36
E	Overhead & Profit			10% x D		243,066.436
F	**Unit Price of Papercrete (D + E)**					**2,673,730.796**

According to the Tables 5.3 – 5.8, Figure 5.8 presents the increasing production cost of papercrete, as follows.

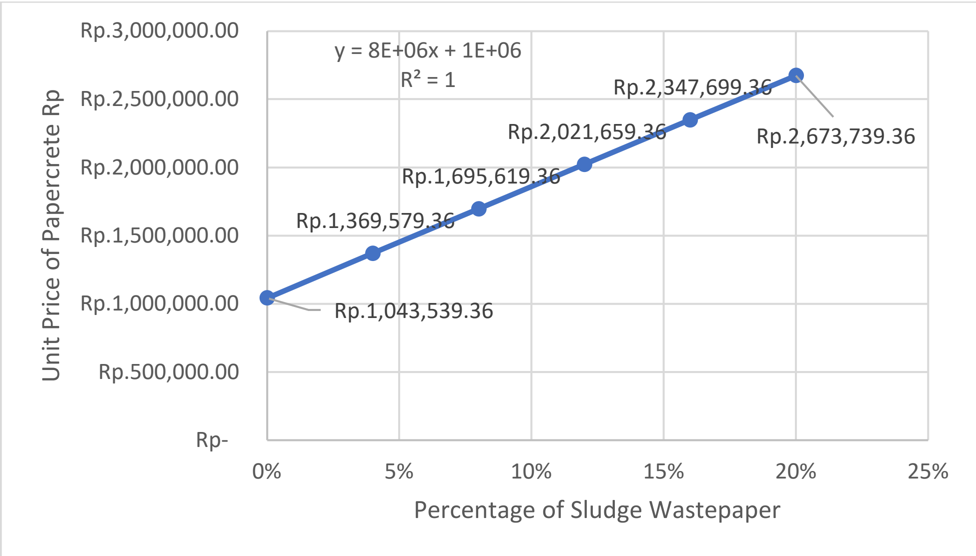

Figure 5. 8 The Increasing of unit price of papercrete along with the increment of sludge wastepaper

Based on Tables 5.3-5.8 shows the results of the calculation of production cost for each mix proportion 0%: 4%:8%:12%:16%:20%. A high % sludge wastepaper value will result in a high cost of papercrete. The lowest cost is in mix 1, namely 0% IDR 1,043,539 and the highest cost value is in mix 6 (20%) IDR 2,673,739. It can be concluded that mix design 6 (20%) is the most expensive among others. The increment of sludge wastepaper takes more cost than normal concrete. The higher composition of wastepaper, the more expensive the papercrete using white wasterpaper. Thus, there is no optimum composition of papercrete production using white waster paper in term of cost of production.

5.4 The Optimum Mix Design

The mix compositions were tested to determine the compressive and flexural strength. The exact compositions were chosen to create a variety of strengths. Compressive and flexural strength are shown in Figure 5.8, where the use of white wastepaper tends to reduce these mechanical properties.

The strength decreases with increasing wastepaper content. Therefore, in terms of strength, there is no optimum composition for papercrete made from white wastepaper. This outcome differs somewhat from earlier studies' conclusions, which found that the optimum percentage of wastepaper is 10% by Solahudin et al. (2023), 5% by Rana (2020), and 11.7% by Tang et al (2020).

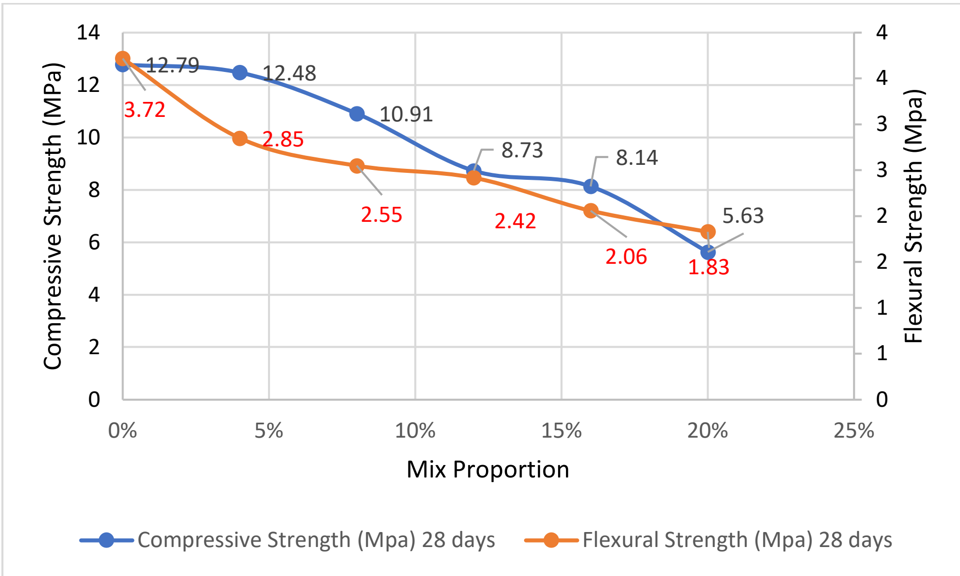

Figure 5. 9 Compressive and flexural strength

Based on compressive dan flexural strength shows on Figure 5.9, at 0% sludge wastepaper has the highest compressive and flexural strength value followed by 4% sludge wastepaper. While the lowest compressive and flexural strength value is at 20% sludge wastepaper. The strength increases caused by the mixed calcium with alumino-siliceous material. The decrease in compressive and flexural strength with the increase in percentage of paper pulp is due to the presence of low silica content in the composition which tends to decrease in its strength. The study found that the demand for water mixing increased with the increasing WPA addition, which was due to the cellulosic fiber materials leading to high water permeability characteristic.

A review of previous studies on the inclusion of WP in concrete, called papercrete, was carried out. It is apparent that the inclusion of paper brought about significant desirable characteristics compared to ordinary concrete. It can also be concluded that paper has the potential to have the favorable properties discussed above. Several experimental studies have shown that 5%–10% replacement of WP with Portland cement and 5%–10% addition of WP in concrete decrease compressive, flexural, and splitting tensile strengths compared to 0% WP content. Generally, it is thought that using WP in the production of concrete is warranted and technically possible, but there are some things to keep in mind to make sure it works well. In this research only used white paperwaste, and can be concluded that, there is not a optimum blend of papercrete made with white waste paper in terms of strength and production costs. For further research needs to explore the utilisation of several other wastepaper.

CHAPTER VI
CONCLUSION

6.1 Conclusion

White wastepaper has been added in concrete ingredients as mentioned papercrete. Based on the results of the discussion of this study, the following conclusions are obtained.

1. The compressive and flexural strengths of papercrete are generally reduced when white wastepaper is used in papercrete ingredient. The strength decreases with increasing wastepaper content.
2. The cost of sludge wastepaper papercrete is higher than that of normal concrete. The cost of papercrete made using white wastepaper increases with its composition.
3. There is not a optimum blend of papercrete made with white waste paper in terms of strength and production costs.

6.2 Suggestion

To maximise the usage of wastepaper from various types of wastepaper (newspaper, magazines, cardboard, office paper, and craft paper), further research needs to be done and compared. To reach the ideal composition of waste paper in terms of mechanical characteristics, more research is required on the size of sludge wastepaper as well as the methods of mixing, compacting, and curing. The utilisation of waste paper is driving up production costs, but there needs to be a greater balance between the cost and the value of papercrete's mechanical characteristics.

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APPENDIX

Appendix 1. Compressive strength for each mix design

No	Test Object Code	Size			Weight	A	P			Average Compressive Strength
		Length	Width	Height						
		Cm	cm	cm	**kg**	**mm²**	**kN**	N	N/mm2	**N/mm² (MPa)**
1	0%_01	15.2	15.2	15.2	7.521	23104	325	325000	14.07	12.79
2	0%_02	15.2	15.2	15	7.496	22800	330	330000	14.47	
3	0%_03	15.1	15.1	15.2	7.549	22952	325	325000	14.16	
4	0%_04	15	15.1	15.1	7.565	22801	280	280000	12.28	
5	0%_05	15.2	15.1	15.2	7.491	22952	300	300000	13.07	
6	0%_06	15	15	15	7.152	22500	310	310000	13.78	
7	0%_07	15.1	15.1	15.2	7.463	22952	240	240000	10.46	
8	0%_08	15	15	15	7.45	22500	220	220000	9.78	
9	0%_09	15	15.1	15.1	7.658	22801	288	288000	12.63	
10	0%_10	15	15.1	15	7.421	22650	298	298000	13.16	

No	Test Object Code	Size			Weight	A	P			Average Compressive Strength
		Length	Width	Height						
		cm	cm	cm	**kg**	**mm²**	**kN**	N	N/mm2	**N/mm² (MPa)**
1	4%_01	15	15.2	15.2	7.289	23104	282.7	282700	12.24	12.48
2	4%_02	15.1	15.25	15.4	7.481	23485	302.1	302100	12.86	
3	4%_03	15.3	15.3	15.4	7.509	23562	247.8	247800	10.52	
4	4%_04	15.2	15.2	15.1	7.293	22952	238.5	238500	10.39	
5	4%_05	15.2	15.2	15.3	7.362	23256	290.7	290700	12.50	
6	4%_06	15.3	15.3	15.4	7.384	23562	326.3	326300	13.85	
7	4%_07	15.3	15.3	15.2	7.336	23256	297.7	297700	12.80	
8	4%_08	15.3	15.25	15.1	7.52	23027.5	310.8	310800	13.50	
9	4%_09	15.3	15.3	15.3	7.346	23409	338.2	338200	14.45	
10	4%_10	15.2	15.2	15.3	7.321	23256	271.9	271900	11.69	

No	Test Object Code	Size			Weight	A	**P**			**Average Compressive Strength**
		Length	Width	Height						
		cm	cm	cm	**kg**	**mm²**	**kN**	N	N/mm2	**N/mm² (MPa)**
1	8%_01	15.2	15.2	15	7.015	22800	261.2	261200	11.46	10.91
2	8%_02	15.2	15.2	15.3	7.203	23256	251.6	251600	10.82	
3	8%_03	15.1	15	15.2	7.025	22800	249.5	249500	10.94	
4	8%_04	15.1	15.1	15.2	7.367	22952	276	276000	12.03	
5	8%_05	15.2	15.2	15.3	7.25	23256	241	241000	10.36	
6	8%_06	15.2	15	15.1	7.104	22650	283.6	283600	12.52	
7	8%_07	15.2	15.2	15.2	7.057	23104	213.4	213400	9.24	
8	8%_08	15.2	15.3	15.2	7.17	23256	255.3	255300	10.98	
9	8%_09	15.1	15	15	6.795	22500	207.2	207200	9.21	
10	8%_10	15.2	15	15.3	7.215	22950	266	266000	11.59	

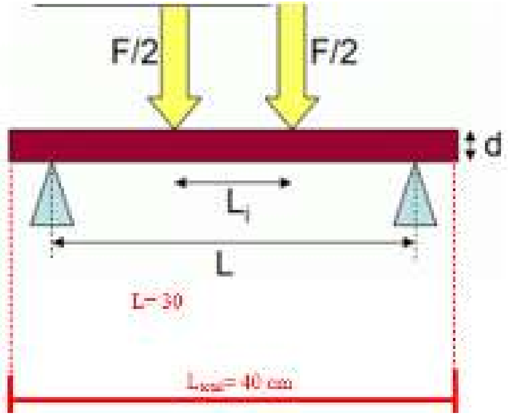
No	Test Object Code	Size			Weight	A	P			Average Compressive Strength
		Length	Width	Height						
		cm	cm	cm	**kg**	**mm^2**	**kN**	N	N/mm2	**N/mm^2 (MPa)**
1	12%_01	15.2	15.2	15.2	6.968	23104	233.3	233300	10.10	8.73
2	12%_02	15.1	15.2	15.1	7.028	22952	167.4	167400	7.29	
3	12%_03	15.2	15.1	15.2	7.136	22952	229.2	229200	9.99	
4	12%_04	15.2	15.2	15.1	7.042	22952	182.8	182800	7.96	
5	12%_05	15.1	15.1	15.1	7.057	22801	131.5	131500	5.77	
6	12%_06	15.1	15.1	15.1	7.164	22801	193.3	193300	8.48	
7	12%_07	15	15.1	15	6.983	22650	203.4	203400	8.98	
8	12%_08	15	15.1	15.1	6.966	22801	188.3	188300	8.26	
9	12%_09	15.2	15.2	15.2	7.13	23104	257.9	257900	11.16	
10	12%_10	15.1	15	15.1	6.891	22650	211.1	211100	9.32	

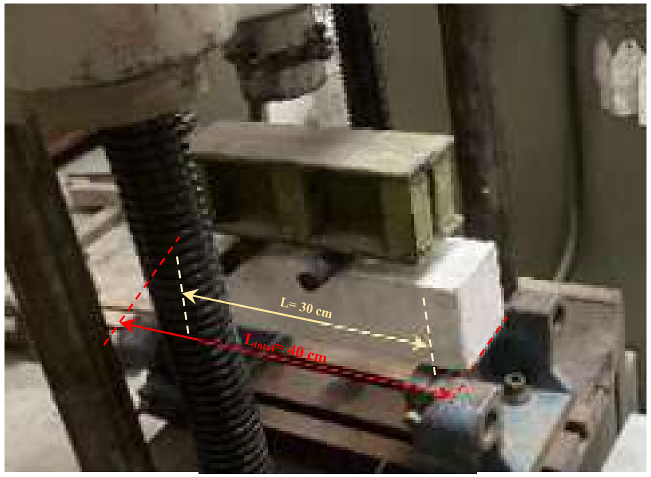
No	Test Object Code	Size			Weight	A	P			Average Compressive Strength
		Length	Width	Height						
		cm	cm	cm	**kg**	**mm²**	**kN**	N	N/mm²	**N/mm² (MPa)**
1	16%_01	15.1	15.2	15.1	7.171	22952	195.3	195300	8.51	8.14
2	16%_02	15	15.1	15	6.905	22650	203.9	203900	9.00	
3	16%_03	15.2	15.1	15.3	7.249	23103	215.2	215200	9.31	
4	16%_04	15.2	15	15.1	7.102	22650	135.6	135600	5.99	
5	16%_05	15.2	15.1	15	7.152	22650	216	216000	9.54	
6	16%_06	15.2	15.1	15.1	7.118	22801	201	201000	8.82	
7	16%_07	15.1	15.1	15	7.243	22650	124	124000	5.47	
8	16%_08	15.1	15.1	15.2	7.082	22952	212	212000	9.24	
9	16%_09	15.2	15.2	15	7.177	22800	176	176000	7.72	
10	16%_10	15	15.1	15	6.888	22650	177	177000	7.81	

No	Test Object Code	Size			Weight	A	P			Average Compressive Strength
		Length	Width	Height						
		cm	cm	cm	**kg**	**mm^2**	**kN**	N	N/mm2	**N/mm^2 (MPa)**
1	20%_01	15.1	15.1	15.1	6.71	22801	111.00	111000	4.87	5.63
2	20%_02	15	15.1	15.2	6.698	22952	121.00	121000	5.27	
3	20%_03	15.1	15.3	15.1	6.598	23103	168.00	168000	7.27	
4	20%_04	15	15	15.1	6.919	22650	134.00	134000	5.92	
5	20%_05	15.1	15.1	15.2	7.011	22952	120.00	120000	5.23	
6	20%_06	15	15.2	15.1	6.897	22952	117.00	117000	5.10	
7	20%_07	15.1	15.2	15	6.814	22800	158.00	158000	6.93	
8	20%_08	15	15	15.1	6.758	22650	152.00	152000	6.71	
9	20%_09	15.2	15.2	15.1	6.864	22952	91.00	91000	3.96	
10	20%_10	15.1	15.1	15.1	7.107	22801	116.00	116000	5.09	

Appendix 2. Flexural strength

Beam under 4 point bending





No	Test Object Code	Size			Weight		Li= (L/3)	(L-Li)	Age	**F**		**Average Flextural Strength**
		L	**W**	**H**							Flextural Strength	
		cm	cm	cm	kg	cm^2	cm	cm		**kN**	**Mpa**	**Mpa**
1	0%_01	30	10	10	8.567	2000	10	20	28	990	29.70	3.72
2	0%_02	30	9.9	10	8.541	1980	10	20		1820	55.15	
3	0%_03	30	10.1	10	8.583	2020	10	20		1250	37.13	
4	0%_04	30	10	10.1	8.794	2040.2	10	20		1275	37.50	
5	0%_05	30	10	10	8.591	2000	10	20		1145	34.35	
6	0%_06	30	9.8	9.9	8.491	1920.996	10	20		950	29.67	

No	Test Object Code	Size			Weight		Li= (L/3)	(L-Li)	Age	F		Average Flextural Strength
		L	**W**	**H**							Flextural Strength	
		cm	cm	cm	kg	cm^2	cm	cm		**kN**	**Mpa**	**Mpa**
1	4%_01	30	10.2	10.3	8.543	2164.236	10	20	28	875	24.26	2.85
2	4%_02	30	10	10	8.514	2000	10	20		765	22.95	
3	4%_03	30	10	10.1	8.482	2040.2	10	20		925	27.20	
4	4%_04	30	10.1	10	8.772	2020	10	20		1250	37.13	
5	4%_05	30	10	10.3	7.983	2121.8	10	20		790	22.34	
6	4%_06	30	9.8	10.2	8.467	2039.184	10	20		1255	36.93	

No	Test Object Code	Size			Weight		Li= (L/3)	(L-Li)	Age	F		Average Flextural Strength
		L	**W**	**H**							Flextural Strength	
		cm	cm	cm	kg	cm^2	cm	cm		**kN**	**Mpa**	**Mpa**
1	8%_01	30	9.9	10	8.355	1980	10	20	28	860	26.06	2.55
2	8%_02	30	10	9.9	8.292	1960.2	10	20		850	26.02	
3	8%_03	30	10	10	8.464	2000	10	20		920	27.60	
4	8%_04	30	10	10.1	8.5	2040.2	10	20		690	20.29	
5	8%_05	30	10	9.8	8.439	1920.8	10	20		795	24.83	
6	8%_06	30	10	10.1	8.295	2040.2	10	20		955	28.09	

No	Test Object Code	Size			Weight		**Li= (L/3)**	**(L-Li)**	Age	**F**		**Average Flextural Strength**
		L	**W**	**H**							Flextural Strength	
		cm	cm	cm	kg	cm^2	cm	cm		**kN**	**Mpa**	**Mpa**
1	12%_01	30	9,9	10	7,971	1980	10	20	28	905	27,42	2.42
2	12%_02	30	10	10	8,09	2000	10	20		615	18,45	
3	12%_03	30	10	10	7,73	2000	10	20		895	26,85	
4	12%_04	30	10,1	10	8,154	2020	10	20		710	21,09	
5	12%_05	30	10,1	10,1	7,952	2060,602	10	20		850	24,75	
6	12%_06	30	10,1	10	8,166	2020	10	20		890	26,44	

No	Test Object Code	Size			Weight		Li= (L/3)	(L-Li)	Age	F		Average Flextural Strength
		L	**W**	**H**							Flextural Strength	
		cm	cm	cm	kg	cm^2	cm	cm		**kN**	**Mpa**	**Mpa**
1	16%_01	30	9,9	10	8,157	1980	10	20	28	740	22,42	2.06
2	16%_02	30	10	10,1	8,096	2040,2	10	20		800	23,53	
3	16%_03	30	10	10	8,053	2000	10	20		640	19,20	
4	16%_04	30	10,1	10	7,983	2020	10	20		455	13,51	
5	16%_05	30	10	10	8,184	2000	10	20		745	22,35	
6	16%_06	30	10	10	8,064	2000	10	20		755	22,65	

No	Test Object Code	Size			Weight		Li= (L/3)	(L-Li)	Age	F		Average Flextural Strength
		L	**W**	**H**							Flextural Strength	
		cm	cm	cm	kg	cm^2	cm	cm		**kN**	**Mpa**	**Mpa**
1	20%_01	30	10,1	10,1	7,831	2060,602	10	20	28	510	14,85	1.83
2	20%_02	30	9,9	10	7,71	1980	10	20		590	17,88	
3	20%_03	30	10	10	7,778	2000	10	20		645	19,35	
4	20%_04	30	10,1	10,1	8,145	2060,602	10	20		635	18,49	
5	20%_05	30	9,9	9,9	7,448	1940,598	10	20		700	21,64	
6	20%_06	30	10,1	10,1	7,918	2060,602	10	20		600	17,47	