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Optimizing concrete strength through pozzolan variation, heat treatment, and alkaline solution modulation: A comprehensive study

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Abstract

The study aimed to assess concrete characteristics and mechanical properties by incorporating pozzolan variations, heat treatments, and alkaline solution molarities. It focused on identifying the optimal pozzolan addition percentage for achieving maximum concrete strength. Specimens underwent heat treatments at 60°C, 90°C, and exposure to alkaline solutions with molarity levels of 6M for rice husk ash and 8M for palm shell ash (PSA). Compressive strength testing at 28 days revealed the most optimal strength of 25.80 MPa in concrete without heat treatment, with 10% Palm Shell Ash pozzolan addition. Non-pozzolan concrete subjected to 1 day of 90°C heat treatment exhibited a strength of 21.99 MPa. The lowest strength observed in concrete without heat treatment, with 15% rice husk ash, resulting in 12.50 MPa. FTIR analysis focused on the chemical aspects of concrete, particularly changes in molecular structure due to different parameters. Composite concrete samples incorporating rice husk ash pozzolan and varying alkaline solution concentrations showed negligible differences. Further analysis found that mixing concrete with 15% Palm shell ash without heat treatment resulted in optimal compressive strength of 22.60 MPa, highlighting PSA's potential in increasing concrete strength. The research also emphasized the effect of temperature on concrete strength, with non-pozzolan concrete heated at 90°C for 1 day showing decreased strength. Comparison of pozzolan influence revealed that Rice Husk Ash tended to reduce concrete strength, especially at higher percentages, indicating a different response to pozzolan types. FTIR analysis identified chemical components in Rice Husk Ash (RHA) pozzolan concrete, laying the foundation for understanding pozzolan-concrete matrix interaction. However, further analysis needed for accurate interpretation of FTIR results and understanding the mechanism behind pozzolan's influence on concrete strength.

1. Introduction

The significance of mineral admixture concrete as a prominent new material globally for both new construction and rehabilitation purposes is evident. The studies indicate that mineral admixtures, including blast furnace slag, fly ash, and silica fume, contribute to the improvement of concrete strength and durability. Ongoing research over years has dedicated to exploring the use of mineral admixtures to enhance concrete properties. Additionally, economic advantages, such as lower cement requirements, and

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environmental considerations, play a crucial role in the increasing utilization of mineral admixtures, [1-5].

The utilization of supplementary cementitious materials (SCMs) in concrete has gained significance due to reasons. Concrete, recognized as the second most utilized material globally, constitutes over 20% of ordinary Portland cement (OPC), raising environmental concerns owing to its association with approximately 8% of worldwide carbon dioxide emissions during manufacturing, [1-3]. In response to the escalating demand in the global construction industry, scholars and academics are actively exploring sustainable alternatives, [4-6].

Over the last few decades, there has been a notable shift towards incorporating supplementary cementitious materials (SCMs), which derived from industrial by-products or natural pozzolan materials, as partial substitutes for cement. These SCMs include fly ash (FA), ground granulated blast furnace slag (GGBS), silica fume (SF), metakaolin (MK), limestone, fine glass powder, among others, [7-9]. This strategic use of SCMs not only contributes to cost reduction in concrete production but also imparts technical advantages, [10-12]. The incorporation of SCMs in concrete shown to decrease the heat of hydration and enhance the overall durability of the concrete structure.

The efficacy of curing practices for pozzolanic cement concrete is a focal point of concern, given the strong dependency of the pozzolanic reaction on proper curing, [13-14]. Over the last few decades, there has been a notable shift towards incorporating supplementary cementitious materials (SCMs), which derived from industrial by-products or natural pozzolan materials, as partial substitutes for cement. These SCMs include fly ash (FA), ground granulated blast furnace slag (GGBS), silica fume (SF), metakaolin (MK), limestone, fine glass powder, among others, [15-19].

Concrete is a highly popular construction material, frequently employed as a key component in building planning and design. This popularity stems from advantages it offers, such as high compressive strength, ease of manufacture and maintenance, the abundance of raw materials in nature, and economic feasibility. Sometimes, to achieve optimal quality in execution, admixtures, fibbers, or non-chemical construction materials can be added with proper proportions and employing appropriate mixing and execution techniques, enhancing the overall result, [20-23].

The Fourier Transform Infrared (FTIR) analysis method utilized to elucidate the chemical aspects of concrete. This involves examining alterations in the molecular structure of concrete induced by various parameters, such as variations in pozzolan, heat treatment, and exposure to alkaline solutions, [24-26].

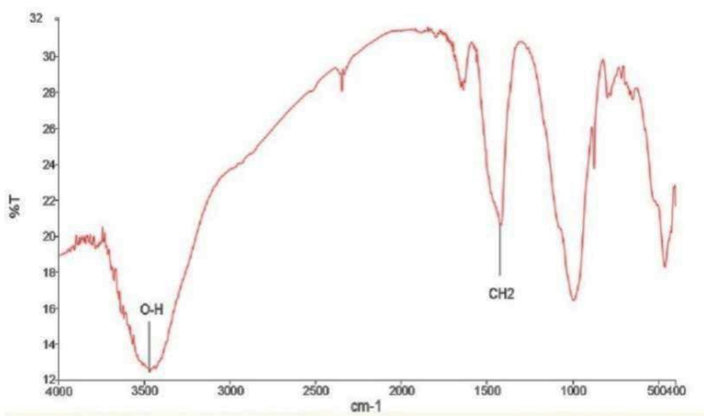

Fig. 1. Compound functional group test results on non-pozzolan concrete by FTIR [27]

Figure 1 displays the results of FTIR testing on concrete without using pozzolan, which only reveals two chemical bonds: O-H and CH_2. This limitation arises because non-pozzolan concrete involves solely a chemical reaction between the cement material and water, with no other chemical reactions occurring. In FTIR analysis, visible absorption bands provide insights into the chemical bonds within the sample. However, interpreting FTIR results for non-pozzolan concrete may be more constrained, often only serving to identify the presence of organic compounds or polymers in the concrete mixture. The research aims to comprehend the characteristics of concrete and its mechanical attributes. This entails examining the influence of varied factors, such as pozzolan variations, various heat treatments, and different molarity levels of alkaline solutions, on concrete properties. The primary objective is to determine the optimal percentage of pozzolan addition for achieving the highest concrete strength.

The materials utilized in this investigation consist of Portland Cement, palm kernel shell ash pozzolan, and rice husk ash, with pozzolan addition percentages varying at 5%, 10%, and 15%. The study involves subjecting concrete specimens to different heat treatments at temperatures of 60°C and 90°C, which is expected to offer insights into the effects of heat on concrete mechanical properties. Compressive Strength Testing: The research includes conducting compressive strength testing at 28 days to evaluate the performance of different concrete mixtures. The goal is to determine the most optimal compressive strength under various conditions. Additionally, the study employs Fourier Transform Infrared (FTIR) analysis to focus on the chemical aspects of concrete. This involves examining changes in the molecular structure of concrete due to different parameters such as pozzolan variations, heat treatments, and alkaline solutions.

Composite concrete, also known as fibre concrete, is a type of concrete reinforced by adding fibres to the concrete mixture. This reinforcement enhances strength, resistance to cracking, and overall mechanical performance. Commonly used fibres include polypropylene, glass, steel, or other types that provide additional support to concrete, [27-29]. Overall, the aim of the study was to investigate factors that can affect concrete strength and then optimize them. By analysing variations in pozzolan use, heat treatment, and modulation of alkaline solutions, the study aims to provide a better understanding of how to improve concrete performance in construction applications. The differences between this study and previous studies. Research Variations: This study includes a wider range of additional variations in terms of the types of pozzolan used (such as rice husk ash and palm shell ash), different heat treatments, and different concentrations of alkaline solutions. This suggests a more comprehensive approach in analysing the influence of factors on the mechanical properties of concrete.

Research Focus: This study focuses more on finding out the optimal pozzolan variation in achieving optimal concrete strength. This suggests that the study has a clearer and more specific focus on identifying the most important parameters in improving concrete strength.

Use of FTIR Analysis: This study also uses FTIR analysis to examine the chemical aspects of concrete, especially changes in molecular structure due to different parameters. This suggests that the study broadens its scope for understanding the chemical interactions between pozzolan and concrete matrices.

Additional Findings: The study found that the addition of oil palm shell ash without heat treatment resulted in optimal compressive strength in concrete, while the addition of rice husk ash tended to reduce the strength of concrete, especially at a higher percentage. This is an additional discovery that provides new insights in the selection of the right pozzolan to improve the quality of concrete.

Research Expansion: Nonetheless, the study also highlights the need for further analysis to interpret FTIR results more accurately and understand the mechanisms behind pozzolan's influence on concrete strength. This suggests that this study provides a foundation for advanced research in this topic.

2. Methods and Mix Design

2.1. Material Preparation

The materials used to make normal-quality concrete include Portland Cement Composite (PCC), coarse aggregate (natural stone), fine aggregate (sand), shell powder, wicker fibre, and water. The cement chosen for this study is PCC cement. Laboratory examination of this cement not conducted because it adheres to standards. Visual inspection will only conduct on the cement bag to ensure there are no damages such as tears and no hard lumps present.

Coarse aggregates derived from natural stone and fine aggregates derived from sand sourced from the KRUENG MEUREUBO River, Aceh Barat Regency. Inspection of coarse aggregates (natural stone) and fine aggregates (sand) as raw materials for concrete requires an examination of physical properties to meet planned standards. This examination includes aggregate properties such as specific gravity, absorption, bulk density, and sieve analysis. Figure 2 shows the process of making an alkaline solution with a molarity of M6, and 10M.

Fig. 2. Preparation of alkaline solutions

Pozzolan Variations is Palm shell ash and rice husk ash. Pozzolan addition percentages is 5%, 10%, and 15%. The objective is to identify the optimum pozzolan content for optimal concrete strength. Heat Treatments, temperatures: 60°C and 90°C. Heat-treated specimens at 1 and 2 days. The goal is to assess the impact of different heat treatments on concrete properties. Alkaline Solutions, molarity levels 6M for rice husk ash and 8M for palm shell ash. The objective is to investigate the influence of alkaline solutions on concrete characteristics. FTIR Analysis, focus on chemical aspects and molecular structure changes. Parameters affecting the molecular structure include pozzolan content, heat treatments, and alkaline solutions. The objective is to understand the chemical variations in concrete due to different parameters. Composite Concrete Samples, incorporate rice husk ash and palm shell ash pozzolan with varying alkaline solution concentrations (0% to 15%). Negligible differences observed in bonding and compound types across concentrations. Image analysis demonstrates uniformity in bonding and compound types.

Figure 3 shows the palm shell ash slag material to use as a binder, and Figure 4 displays Rice Husk Ash. Firstly, 'palm shell ash' refers to the ash from palm kernel burning, while 'Rice Husk Ash' derived from burned rice husks. These materials used as binders in composite concrete. Here are their potential benefits and uses, palm shell ash Slag. This material can provide additional strength to concrete, making it more resistant to pressure and loads. Utilizing palm shell ash and slag as binders can aid in waste utilization and support recycling practices. Rice Husk Ash can help reduce pores in concrete, increasing material density and strength. The use of rice husk ash in composite concrete can reduce the need for conventional materials, thereby improving the energy efficiency of concrete production. The use of these two types of ash as binders in composite concrete can offer economic and ecological advantages. However, it is crucial to note that the formulation and proportions of these ingredients must carefully considered to ensure the desired mechanical and functional properties of concrete. Laboratory tests and analysis also required to validate the performance of composite concrete using these materials.

Fig. 3. Slag from burning palm shell ash

Fig. 4. Rice Husk Ash

Figure 4 shows the location of the rice processing plant, where Rice Husk Ash (RHA) waste observed utilized as a natural pozzolan in the production of composite concrete. This process involves incorporating an RHA binder and an alkaline solution, with sodium silicate serving as an activator.

2.2 Mix Design

The research will employ a concrete mixture with a targeted strength of 20 MPa. The concrete mix design methodology follows the guidelines outlined in the American Concrete Institute (ACI) 211.1-22 standard. The standard specimen for testing will be cylindrical, with a diameter of 15 cm and a height of 30 cm, and it will contain aggregate with a maximum diameter of 19 mm.

The design of the test specimens in this study includes evaluating the characteristics and mechanical properties of concrete with variations in the addition of pozzolan, different heat treatments, and variations in the molarity of alkaline solutions. The following outlines the design of the test specimens, including the materials used: Portland Cement, Palm Shell Ash, Pozzolan Rice Husk Ash, and aggregate. Pozzolan addition variations are set at 5%, 10%, and 15%, while heat treatments are conducted at 60°C and 90°C. The alkaline solution has a molarity of 6M for rice husk ash and 8M for palm shell ash. Test specimen creation involves mixing concrete with varying percentages of pozzolan addition. Concrete specimens then created and grouped based on heat treatment conditions and alkaline solution concentrations. Detailed information about the test specimens provided in Table 1.

Table 1. Test specimen design

Specimens	Age of test	Molarity Alkaline			Thermal Curing		
Concrete Cylinder	Day	0 M	6 M	8 M	Thermal		
		I	II	III	0°C	60°C	90°C
CRHA 0%	14 Days	3	0	0	0	1 D 60°C	2 D 90°C
	28 Days	3	0	0	0	1 D 60°C	2 D 90°C
CRHA 5%	14 Days	0	3	0	0	1 D 60°C	2 D 90°C
	28 Days	0	3	0	0	1 D 60°C	2 D 90°C
CRHA 10%	14 Days	0	3	0	0	1 D 60°C	2 D 90°C
	28 Days	0	3	0	0	1 D 60°C	2 D 90°C
CRHA 15%	14 Days	0	3	0	0	1 D 60°C	2 D 90°C
	28 Days	0	3	0	0	1 D 60°C	2 D 90°C
Total specimens		6	18				
CPSA 5%	14 Days	0	0	3	0	1 D 60°C	2 D 90°C
	28 Days	0	0	3	0	1 D 60°C	2 D 90°C
CPSA10%	14 Days	0	0	3	0	1 D 60°C	2 D 90°C
	28 Days	0	0	3	0	1 D 60°C	2 D 90°C
CPSA 15%	14 Days	0	0	3	0	1 D 60°C	2 D 90°C
	28 Days	0	0	3	0	1 D 60°C	2 D 90°C
Total specimens				18			

For test specimens without the addition of pozzolan and alkali solution, there are 6 pieces. Evaluate specimens with the addition of rice husk ash (RHA) and using alkaline solution with a 6M molarity consist of 18 test specimens. Assess specimens with Palm Shell Ash (PSA) pozzolan and alkaline solution with an 8M molarity also consist of 18 test specimens. For more details, refer to Table 1, which shows variations in the addition of pozzolan, variations in heat treatment, variations in the heating period, as well as variations in heating temperature.

In this study, Super Plasticizer used at a rate of 1% of the weight of cement, which amounts to 0.127 kg, for each variation with the addition of pozzolan, except for concrete with 0% pozzolan, where super plasticizer not added. The cement used in this study is Portland Composite Cement class 2.

Table 2. Mix design

No	Specimen	Materials					
		Cement	Pozzolan	water	Fine aggregate	Coarse Aggregate	Alkaline solution
		(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
1	CRHA 0%	12.717	0	6.613	16.760	25.179	0.24
2	CRHA 5%	12.717	0.64	6.613	16.478	24.717	0.24
3	CRHA 10%	12.717	1.27	6.613	16.170	24.255	0.24
4	CRHA 15%	12.717	1.91	6.613	15.682	23.793	0.24
5	CPSA 5%	12.717	0.64	6.613	16.478	24.717	0.24
6	CPSA10%	12.717	1.27	6.613	16.170	24.255	0.24
7	CPSA 15%	12.717	1.91	6.613	15.682	23.793	0.24
	Totals	89.190	7.63	46.29	113.426	170.709	1.68

2.3 Compressive Strength Testing

The Indonesian National Standard (SNI) is a set of technical guidelines published by the National Standardization Agency (BSN) in Indonesia. SNI 03-2834-2000 is the standard for testing the compressive strength of concrete in Indonesia, [30-33]. The following provides an explanation of concrete compressive strength testing based on SNI. The primary purpose of compressive strength testing of concrete is to determine its resistance to applied pressure, ensuring that the concrete used in construction meets established strength standards. Before the test begins, concrete specimens must be prepared in accordance with the provisions outlined in the SNI (National Indonesian Standard). This includes selecting the size and shape of the specimen to be representative of the structure or concrete work to evaluated.

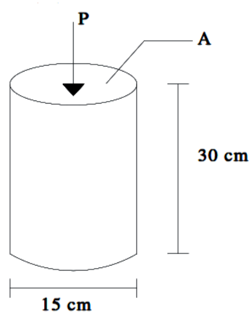

Fig. 5. Specimen setting for compression test [35]

Concrete compressive strength testing conducted using a concrete compressive testing machine. The concrete specimen placed inside the testing machine and subjected to a gradually increasing load until failure occurs. The load measured and recorded during the test. Two types of specimens commonly used: concrete cylinders (with certain diameters and heights) and concrete cubes (with specific sides). SNI provides guidance on selecting specimen types based on specific project needs or conditions. Compressive Strength Measurement: Test results expressed in units of pressure (MPa) or N/mm^2, representing the maximum compressive strength a concrete specimen can withstand before failure. This value offers a reliable indication of concrete strength under certain conditions. SNI sets the minimum limit of compressive strength that concrete must meet to accept in construction projects. If the compressive strength value of concrete meets or exceeds the limit, the concrete considered to meet the standard requirements.

Test results reported in full, including information about the concrete specimen, test conditions, loads applied, and compressive strength values obtained. This report is useful for documenting and evaluating the quality of the concrete used. It is important to always refer to the latest version of the applicable SNI standard, as test requirements and procedures may change over time. Figure 5 shows the setting of the specimen in the compressive strength testing process [35].

Room conditions for the tested sample. This is important because room conditions can affect test results and data consistency. The examples of specifications that included in room conditions are. Temperature: For example, the room is set at a certain constant temperature, such as 25°C, to ensure consistency in the test. The relative humidity of a room can also be set to remain constant, for example, at 50% RH, to minimize the influence of humidity on the sample. If the test requires visual observation, the light intensity in the room should be set consistently to ensure uniform test conditions. In cases, such as testing materials under certain conditions, atmospheric pressure in the room can be set to meet the test requirements. Other factors such as ventilation, noise, and environmental contamination also need to consider and regulated if possible.

2.4 FTIR Testing

FTIR (Fourier Transform Infrared Spectroscopy) testing on geopolymer concrete is an infrared spectroscopic analysis method used to understand the chemical composition and molecular structure of geopolymer concrete, [36]. Geopolymer concrete, a type of concrete that utilizes geopolymer binders instead of conventional Portland cement, is examined through FTIR to provide insights into the chemical bonds between atoms in geopolymer concrete samples, [37].

FTIR spectrum analysis provides valuable insights into the chemical structure and composition of geopolymer concrete. Peaks in the spectrum offer clues about the chemical bonds and molecules present in the sample. FTIR results are instrumental in verifying the presence of the desired geopolymer in concrete, with specific peaks ensuring the proper formation of geopolymer bonds. By delving into the molecular structure and composition of materials, FTIR testing on geopolymer concrete contributes to a deeper understanding and aids in the development and refinement of geopolymer concrete performance, [38].

Fig. 6. Sample preparation for FTIR testing

Here are the general steps involved in FTIR testing on geopolymer concrete. Sample preparation, geopolymer concrete samples crushed into a fine powder, as shown in Figure 6. The concrete powder then placed on a transparent substrate suitable for FTIR analysis, such as glass or calcium fluoride. Spectrum measurement, the sample positioned inside the

FTIR spectrometer. Infrared light directed to the sample, and the resulting infrared spectrum recorded. This process measures a series of intensified waves produced by chemical bonds in the sample. The resulting spectrum shows peaks associated with specific chemical bonds in the sample. These peaks identified and associated with specific components in geopolymer concrete, such as Si-O-Si (silica) bonds, Al-O-Si (aluminosilicate) bonds, and geopolymer bonds.

3. Results and Discussion

The research aimed to examine the attributes and mechanical behaviours of concrete in various scenarios, including changes in pozzolan levels, heat treatments, and alkaline solution concentrations. The primary focus was on determining the most effective amount of pozzolan addition for enhancing concrete strength. Portland Cement, palm kernel shell ash pozzolan, and rice husk ash utilized as materials, with pozzolan ratios set at 5%, 10%, and 15%. Figure 7 shows the condition of the composite concrete specimen after compressive testing, experiencing columnar cracking which means its strength is not too high because it undergoes heating for two days with a temperature of 90^0C. Where the age of testing at the age of 14 days.

Fig. 7. Sample concrete after compression test

After subjecting the specimens to different treatments, the compressive strength testing at 28 days revealed notable findings. The most optimal compressive strength of 22.60MPa observed in concrete without heat treatment, with the addition of 15% palm shell ash (PSA) pozzolan. The compressive strength of non-pozzolan concrete subjected to 1 day of heat treatment at 90°C was slightly lower at 21.99MPa. On the contrary, the lowest compressive strength observed in concrete without heat treatment, with the addition of 15% rice husk ash, resulting in a compressive strength of 12.50MPa. More details of compressive strength test results with pozzolan variations, differences in alkaline solution molarity, and heat treatment shows in Table 3 and Figure 8.

Table 3 shows that the data include research results related to the strength of concrete containing various percentages of Concrete Rice Husk Ash (CRHA) and Concrete Palm Shell Ash (CPSA) under different concrete aging conditions (test life) and various thermal treatment conditions. The compressive strength of concrete measured in Megapascals (MPa). In the data matrix, the numbers represent the compressive strength of concrete under specific conditions. For example, on the 0% CRHA line with Thermal Curing II (60°C) and a test life of 14 days, the compressive strength of concrete is 19.84 MPa. In the matrix, general findings drawn. In general, the addition of CRHA (Residue High Alumina) shows a decrease in concrete strength, especially at higher percentages. This observed in rows with CRHA percentages (5%, 10%, 15%) under various thermal treatment conditions. In general, the addition of CPSA shows variations in concrete strength, depending on the percentage and thermal treatment conditions.

Table. 3 Compressive strength test results

Specimens	Age of test	Molarity Alkaline			Thermal Curing			Strength (MPa)		
Concrete Cylinder	Day	I	II	III	I	II	III	I	II	III
		0 M	6 M	8 M	0°C	60°C	90°C			
CRHA 0%	14 Days	3	0	0	0 D	1 D	2 D	19.84	14.70	12.55
	28 Days	3	0	0	0 D	1 D	2 D	20.10	21.99	17.70
CRHA 5%	14 Days	0	3	0	0 D	1 D	2 D	15.55	18.10	19.80
	28 Days	0	3	0	0 D	1 D	2 D	17.27	20.11	21.20
CRHA 10%	14 Days	0	3	0	0 D	1 D	2 D	12.20	8.90	15.60
	28 Days	0	3	0	0 D	1 D	2 D	16.70	15.50	17.80
CRHA 15%	14 Days	0	3	0	0 D	1 D	2 D	12.60	17.40	20.02
	28 Days	0	3	0	0 D	1 D	2 D	12.50	15.60	18.70
CPSA 5%	14 Days	0	0	3	0 D	1 D	2 D	17.70	14.90	13.80
	28 Days	0	0	3	0 D	1 D	2 D	21.70	15.90	12.60
CPSA10%	14 Days	0	0	3	0 D	1 D	2 D	25.30	9.80	15.40
	28 Days	0	0	3	0 D	1 D	2 D	25.80	21.30	20.00
CPSA 15%	14 Days	0	0	3	0 D	1 D	2 D	17.80	16.80	11.30
	28 Days	0	0	3	0 D	1 D	2 D	22.60	17.50	19.10

The optimal strength achieved in PSA pozzolan concrete with a 10% addition at the age of 28 days, exhibiting a heat treatment rate of 25.8 MPa. Conversely, the lowest compressive strength was observed in non-pozzolan concrete at the age of 14 days, subjected to a heat treatment of 60°C for 1 day. In the case of RHA pozzolan concrete, the most favourable strength was attained at the age of 28 days with a two-day heat treatment, while the weakest strength occurred at the age of 14 days with a heat treatment of 60°C for one day, registering at 8.9 MPa. For PSA pozzolan concrete, the lowest compressive strength was recorded at a heat treatment of 60°C for one day, with a testing duration of 14 days.

From Figures 1, 9 and 10 it can be seen that there are differences in compound functional groups Where in Figure 1, namely concrete without additional pozzolan there are only O-H and CH_2 compound bonds, while in figures 9 and 10 show the addition of compound functional groups, namely there are two O-H bonds, then the presence of C=O and CH_3 bonds, this shows that concrete with additions has additional compound functional groups that contribute strength to concrete with the addition of material Pozzolan. Pozzolan PSA is more suitable for addition to composite concrete because it has more calcium oxide content than RHA, so PSA is more concrete which proven from variations in heating tests resulting in PSA concrete decreasing in strength when heated. Conversely, in RHA there are more silica elements so that it is more influential on the polymer process, this can be proven by heating variations, where RHA concrete experiences an increase in compressive strength when applied, although overall the compressive strength produced by RHA concrete does not increase too much compressive strength compared to PSA concrete.

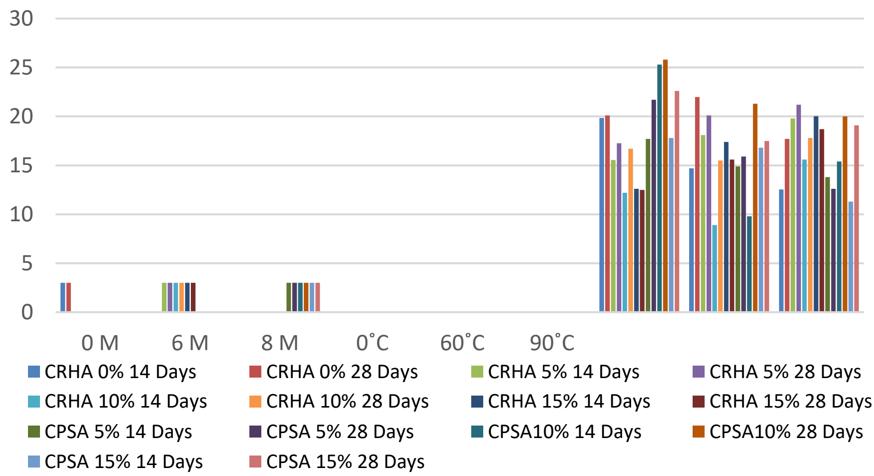

Fig. 8. Compressive strength relationship with age of testing, heat treatment and molarity of alkaline solutions

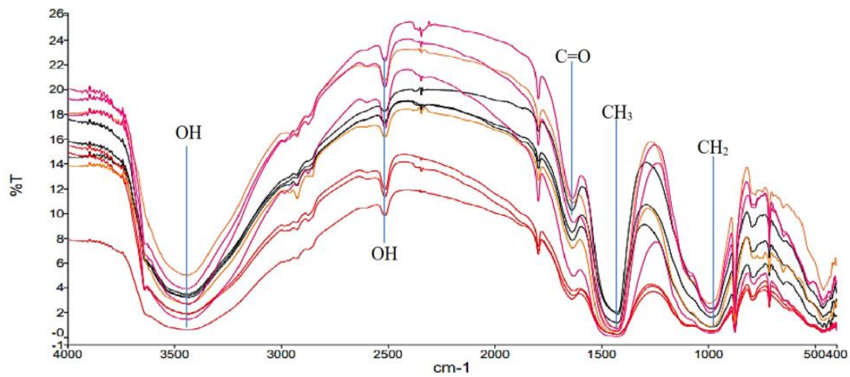

Fig. 9. FTIR test results on RHA and PSA pozzolan concrete

Fig. 9 show the wavenumbers of the test results from FTIR. In Figure 10 of RHA and PSA pozzolan concrete shows the occurrence of 5 groups of chemical compounds, namely O-H, O = H, C = O, CH_3, and CH_2. FTIR (Fourier Transform Infrared) testing is an infrared spectroscopy method used to analyse molecular structures based on the absorption of infrared light by molecules. The wavenumber recorded in FTIR test results can provide information about functional groups in a compound.

Here are common interpretations of compound groups that shows in the FTIR results of pozzolan concrete RHA (Rice Husk Ash): O-H (Hydroxyl): The wavenumber range is about 3200-3600 cm^{-1}. Hydroxyl can come from water or from hydroxyl groups in organic compounds. O=H (Hydroxy Group): The wavenumber range is about 3000-3500 cm^{-1}. This group can also refer to hydroxyl, especially hydroxyl bonded to oxygen atoms in compounds. C=O (Carbonyl Group): The wavenumber range is about 1700-1750 cm^{-1}. The carbonyl group derived from compounds such as ketones or aldehydes. CH_3 (Methyl): The wavenumber range is about 2800-3000 cm^{-1}. This indicates the presence of methyl groups in the compound. CH_2 (Methylene): The wavenumber range is about 2800-3000 cm^{-1}. This group indicates the presence of a carbon chain consisting of two carbon atoms. FTIR results reflecting the presence of these groups can provide information on the chemical composition and molecular structure of RHA pozzolan concrete. However, a more detailed and accurate interpretation requires a further understanding of the test conditions and the specific characteristics of the sample assessed.

4. Conclusions

The objective of the research was to evaluate the properties and compressive strength of concrete incorporating different proportions of pozzolan additives, namely palm kernel shell ash (PSA) and rice husk ash (RHA), under various thermal treatment conditions and concentrations of alkaline solution. From the results and distribution data, the following conclusions drawn:

- Concrete without pozzolan, subjected to 1 day of heat treatment at 90°C, exhibited a slightly lower compressive strength of 21.99 MPa.
- The lowest compressive strength observed in concrete without heat treatment, with the addition of 15% rice husk ash, recording at 12.50 MPa.
- Pozzolan Effects: The addition of Concrete Rice Husk Ash (CRHA) led to a decrease in concrete strength, especially at higher percentages, under various thermal treatment conditions.
- Concrete Palm Shell Ash (CPSA) addition showed variations in strength, depending on the percentage and thermal treatment conditions.
- Optimal Conditions: The highest compressive strength 25.8MPa achieved in PSA pozzolan concrete with a 10% addition at the age of 28 days.
- The weakest strength occurred in non-pozzolan concrete at the age of 14 days, subjected to a heat treatment of 60°C for 1 day.
- FTIR Analysis: FTIR analysis revealed chemical compounds in RHA pozzolan concrete, including O-H, O=H, C=O, CH_3, and CH_2 groups.
- Interpretations of wavenumbers suggested the presence of hydroxyl, hydroxy groups, carbonyl groups, methyl groups, and methylene groups in the RHA pozzolan concrete.
- Detailed analyses, considering specific test conditions and sample characteristics, required for a more accurate interpretation of FTIR results.

In summary, this study provides valuable insights into the impact of pozzolan addition, thermal treatment, and alkaline solution molarity on the characteristics and compressive strength of concrete, offering a foundation for future research in optimizing concrete mixtures for enhanced performance. Recommendations for Further Research: Further investigations needed to understand the specific mechanisms behind the observed effects of pozzolan on concrete strength.

The novelty of this research lies in its comprehensive investigation into the properties and compressive strength of concrete incorporating various proportions of pozzolan additives, specifically palm kernel shell ash (PSA) and rice husk ash (RHA), under diverse thermal treatment conditions and alkaline solution concentrations. The key findings contribute to advancing the understanding of pozzolan effects on concrete performance in significant ways:

- Effect of Thermal Treatment: The study elucidates how different thermal treatment conditions impact concrete strength, highlighting variations in compressive strength under distinct temperatures and durations.
- Pozzolan Influence: By analysing the effects of CRHA and CPSA additions on concrete strength, the research identifies trends in strength variations, particularly emphasizing the decrease in strength associated with higher percentages of CRHA addition.
- Optimal Conditions: The identification of optimal conditions for achieving the highest compressive strength, notably 25.8 MPa in PSA pozzolan concrete with a 10% addition at 28 days, offers valuable insights for concrete mixture optimization.
- FTIR Analysis: The use of FTIR analysis to characterize chemical compounds in RHA pozzolan concrete unveils molecular changes, providing a deeper understanding of the interaction between pozzolan additives and the concrete matrix.
- Recommendations for Further Research: The call for further investigations into the specific mechanisms behind observed pozzolan effects on concrete strength sets the stage for future studies aimed at unravelling the underlying mechanisms and optimizing concrete mixtures for enhanced performance.

This research fills gaps in current knowledge by systematically examining the impact of pozzolan additives, thermal treatment, and alkaline solution molarity on concrete properties and compressive strength, laying a foundation for future endeavours in the field of concrete material science and engineering.

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