Effect of reduction of heat using Kenaf fibrous pulverised fuel ash concrete in hydration process

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Abstract. Since early civilization, the toughness of concrete Pozzolanic materials, either naturally occurring or artificially produced, has long been in practice. The purpose of pozzolanic materials in the cement industry especially contributes to strengthening the concrete structure after its reaction with water. However, the increase in temperature of the cement mixture after the addition of water becomes a great concern. Which can affect the quality of the structure afterward. Therefore, this research mainly focuses on the study of the heat of hydration process in the early stages of a concrete mixture. Four types of concrete mixtures are used in this study are Ordinary Portland Cement concrete (OPC), pulverised fuel ash cement concrete (PFAC), Kenaf fibrous concrete (KFC), and Kenaf pulverised fuel ash concrete (KFPC). The temperature of all samples was recorded for 72 hours. The selection of pozzolanic material of PFA cement in the mixture was found to play an important role in controlling the heat. The result indicated that the replacement of 25% of PFA (for PFAC sample) and addition of Kenaf fiber (for KFC sample) in the concrete mixture reduced the heat of hydration by 5% and 3% respectively, compared to the conventional OPC mixture. Thus, the combination of PFA and Kenaf fiber in one concrete mixture can result in a 6% reduction of the heat of hydration. Hence, the partial replacement of cement with pulverised fuel ash and kenaf fiber is beneficial, especially for mass concrete where it can minimize the effect of thermal cracking of the structure due to excessive heat rise.

1.0 Introduction

Kenaf (Hibiscus cannabinus L.) is one of the crop plantations that have a great potential for multiple uses in industrial composites, fabric, paper, board, and building construction. This crop can produce fiber that can be a raw construction material through the thermochemical process. Kenaf has been a promising sustainable raw material for pulp and others. It is a multi-purpose crop and can provide the raw material for industrial and energy applications. The uniqueness of this fiber can be used by its bark about 30-40% for several high-value fiber applications [1]. In this study, what is more, the concern is the performance of fibrous concrete as a composite material in building construction. This research aims to investigate the hydration process of kenaf fibrous concrete and kenaf pulverised fuel ash concrete compared to normal concrete. The matric composition contains pozzolanic material that has been identified to reduce temperature while hydration unlikely OPC will reach the ultimate temperature because of Calcium Hydroxide along the process. Hence, the addition of Kenaf fiber and Fuel Ash cement will determine the capability of the composite in the hydration process.
Indications of kenaf being put forward as a possible option for fiberboard processing for panel products became official under the 7th Malaysian Plan in the late 1990s, and now it is being researched for potential uses under the 21st Malaysian Plan [2]. The Malaysian Ministry of Plantation Industries and Commodities (MPIC) has identified six key strategic areas for the development of the kenaf industry, including increasing kenaf productivity and production, improving research, development, and commercialization, encouraging commercial kenaf production, expanding on-stream industries, and promoting the use of kenaf and kenaf products. It has been described as one of the latest growth items in Malaysia, where previously unutilized crops such as hemp, jute, wool, and bamboo are planted to create “new value.” Kenaf is to be introduced in Pahang, Kelantan and Melaka, as well as Terengganu, Perak, and Johor. The market for kenaf fibre and core as automotive materials, bio-fibers, and pulp has significantly increased due to their high environmental benefit, energy usage, bio-compos, and paper suitability.

According to the MPIC, living room panels, wall panels, and stairs are now being made from kenaf polymer fibre obtained a well-deserved reputation, and was then a common building material for making all three different building components. Kenaf as a new additive has the potential for use in renewable, “green” CO₂-sequestration concrete made from the atmosphere, which could also potentially be a better substitute for tobacco industry uses today [3]. Unfortunately, the usage of cement in the Kenaf Fiber Concrete production phase generates more CO₂. Furthermore, future studies could concentrate on mineral admixtures that will help in the need for cement while assessing their effect on the life cycle from start to finish. As observed in the research and experiments with the ingredient of kenaf, the addition of fibre results in concrete results in additional efficiency for the complex and mechanical properties. Kenaf is not only showing potential in the United States but is also being studied as a multipurpose commodity in several other countries around the world.

Finally, since this crop is currently interesting to researchers in many other countries and countries, and in the U.S. for several years, researchers, expansion has drawn their focus. So many observers believe that kenaf appears to stick out in the eyes of the government from a host of grants and support programs such as the Malaysian Timber Board's and the National Tobacco Board's (MARDI) invested in the seed. There is approximately 35 million RM [Malaysian Ringgit] worth of Ninth Malaysia's Research and Development grants allocated to date for kenaf planting. The UN Industrial Development Organization (UNIDO) supported the mission when it was awarded a grant from the Netherlands-based Commodities Fund for the production and promotion of kenaf through field-tested surveys and pilot programs.

1.1 Natural Fibrous Properties
The studies done by [4] revealed that fibre reinforced concrete (FRC) with a steel fiber ratio of 0.5% to 2% had the best overall performance. The investigation of fibre surface treatment and volume fraction in non-woven mats with a wetting agent-infused fibre material after undergoing a four-point-bending test and proving to be 40 percent stronger in flexural fractional [5]. The matrix composites were 25 times tougher, and 20% more stable. Notably, the performance of natural fibre was on a par with other synthetic fibres. Table 1 shows the research of the study on Kenaf Fiber Reinforced Concrete (KFRC). Mechanical properties performance has been determined using different parameters. The results from all researchers indicate that the inclusion of KFRC does not improve the flexural and compression strength but showed improvement in tensile strength. KFRC increases the toughness and ductility based on the distribution of crack. The inclusion of fiber length and fraction mostly in the same quantity as shown in table 1. However, they come out with a different optimum value of fiber length and fraction. The fiber length mostly used by the researcher was between 25 and 50mm and the optimum value was 0.5% and 1%.
Table 1. Research of study on Kenaf Fiber Reinforced Concrete

| References | Types | Fiber Length (mm) | Fiber Volume Fraction/Fiber Content | Aggregates | Optimum value fiber volume fraction and fiber length |
|------------|-------|-------------------|------------------------------------|------------|-----------------------------------------------|
| [6]        | KFRC  | 0.25, 30, 35      | 0%, 1%, 2%, 3%, and 4%             | Sand       |                                               |
| [7]        | KFRC  | 25 mm and 50 mm   | 0.5%, 0.75%, 1.0%, 1.5%, and 2.0% | 10mm       | 0.75% and 50mm                               |
| [3]        | KFRC  | 25 to 38 mm       | 1.2% and 2.4%                      | 9.5mm      | 1.2%                                          |
| [8]        | KFRC  | a mixture of 20mm and 50mm | 0%, 1%, 3% and 5% | 10mm | 1.0%                                          |
| [9]        | KFPC  | 25mm and 50mm     | 0.5%, 0.75%, 1%, and 1.5%          | 10mm       | 0.75% and 25mm                               |

The performance of biocomposites depends on the properties of the fibers used in them. However, using fibers in building materials has also some disadvantages such as low modulus elasticity, high moisture absorption, decomposition in alkaline environments or a biological attack, and variability in mechanical and physical properties [10]. Fibre from the Kenaf plant can be divided into short and long fiber measured by aspects ratio. Fibre behaviour in strengthening the composite, presently research by [3] says that kenaf fiber reinforced concrete can be used as strengthening materials for reinforced concrete (RC) beams.

Concrete is a composite that remarkably good in compression but low in tensile strength. In the last few years, because of the increasing environmental concern, the utilization of fibres from natural resources (i.e. vegetable fibres) to replace synthetic carbon/glass fibres for fibre reinforced polymer (FRP) composite application has gained popularity [11]. Natural fibres, e.g. flax, hemp, jute, coir, and sisal, are cost-effective, have high specific strength and specific stiffness and are readily available [12].

Natural fiber has characteristics of high moisture absorption that may reduce the mechanical properties of concrete. In order to corporate the natural fiber with concrete, the physical and chemical treatment of fiber is a must to overcome the adhesion of fiber-matrix in a composite [13]. The natural fibers are rich in cellulose, hemicelluloses, lignin, and pectins, all of which are hydroxy 1 groups; they are usually hydrophilic sources and strong polar. Alkali treatment will innovate the fiber, therefore, may overcome the interfacial bonding problem [14,15]. Thus, there are major challenges of suitability between the matrix and fiber that weakens the interface region between matrices and natural fibers [16]. In a study done by Cheung et al., [17] the interfacial bonding of natural fiber and stress transfer properties in solving environmental problems have not yet been solved to date. This study shows that the major concern is the compatibility bonding of addition materials (natural fiber) to the concrete mixture. Less research about the fiber specification and fibrous concrete performance toward the environment in long term duration [18].

1.2 Problem Statement

The composite's output is more easily described as the properties of the concrete, in combination with the reinforcing fibres. The capacity to compose as lower in elasticity, strong moisture absorption, alkaline disintegration, and susceptibility in engineering properties was distracted by natural fibres [10]. Kenaf fibres may be separated by their aspect ratio into various measurement fibres. Composite enhancement behaviour, currently researched by Elsaid et al., [3], indicates that the kenaf fibre concrete beams were comparable for increasing the material strength properties. A study recorded less long-term fibre specification and fibre concrete efficiency analysis [18]. There
are few existing research on the composition of the kenaf fiber-reinforced concrete in practice for the concrete mix design and assessment of the durability in long-term performance [19].

The hydration of concrete is primarily governed by materials and mix characteristics. The heat of hydration of a cement happens when the compound is reacted with water to stabilize the hydrated state of matter and similarly to the variations of chemical compositions in other composites hence, the chemical interactions are taken into consideration. Calcium is the major ingredient in Portland cement; thus, the amount of total heat generated will be affected Concrete with a high cement content might have benefits in the beginning, but a rise in temperature due to the chemical reactions causes unwanted and unpredictable cracking [20,21,22].

2.0 Materials and method

2.1 Raw Materials
There are four types of concrete mixes were prepared in this study, which is Ordinary Portland Cement (OPC) from Tasek Corporation as normal concrete, Pulverised Fuel Ash Concrete (PFAC) from Tanjung Bin Power Plant, Pontian, Johor, Kenaf fibre with OPC was called Kenaf Fibrous Concrete (KFC) and Kenaf Pulverised Fuel Ash Concrete (KFPC) was the combination of kenaf fibre and PFA cement. Table 2 shows the concrete mix proportion of the concrete mixture. Sieve analysis for the aggregate size of 10mm was referred to ASTM C136-06 for this experimental program.

| Constituent material | Proportions KFC (kg/m³) | Proportions KFPC (kg/m³) |
|----------------------|------------------------|------------------------|
| Cement               | 463                    | 347.3                  |
| Fly Ash              | -                      | 115.7                  |
| Fine aggregate       | 800                    | 800                    |
| Coarse aggregate     | 867                    | 867                    |
| Water                | 250                    | 250                    |
| Kenaf Fibre 0.5%, 0.75%, 1%, 1.5% | 6,9,12,15 6,9,12,15 |
| Super plasticiser    | 4.63                   | 4.63                   |

2.2 Kenaf Fiber Treatment
This treatment plan for this fiber using 5% of sodium hydroxide (NaOH) concentration was carried out to remove hemicellulose, pectin and lignin form the raw fiber [18,23]. The fiber were soaked in the NaOH for three hours at room temperature, then were rinsed and immersed in water for 24 hours. The fiber must be dried for 3 days as it ready to be used. The National Kenaf and Tobacco Board of Kelantan, Malaysia, is the main contributor to kenaf fibre used in this research.

2.3 Research Method
Hydration happens when concrete starting to set. In the process of release heat, cement has increased the temperature and rate of hydration. The fundamental property of hardened concrete can be achieved by this testing. A rectangular plywood box size 470 × 240 × 150 mm height with the 10mm of polystyrene as insulation that covers the box was prepared. OPC concrete mixes and KFC concrete were cast in the three-gang plastic mould. Samples for PFAC and KFPC for the second batch of testing were prepared with the same procedure. Half of the concrete mix was poured inside the mould and a thermocouple type K was inserted at the centre of the mould, then the balance of concrete has fully covered the mould. The box then was covered tightly with masking tape and initial data will be started to be measured. The thermocouple connected to the data logger and the temperature data were recorded at 10 minutes interval and was continued up to 72 hours. The testing
setup as shown as Figure 1. This method was referred by present studies [22] of hydration process of concrete.

![Figure 1. The setup for hydration testing](image)

### 3.0 Results and Discussion

The principal objective in utilizing Fly Ash is to consider using an offensive and durable pozzolanic substance. Cement from Tanjung Bin Power Power Plant, Pontian, is class F, with a chemical composition that is about 70% compared to ASTM C618 of silica, alumina and iron oxide [24]. The substitution of 25% of the weight of cement in this study was used to observe the PFA pozzolanic reaction in the hydration process. The lower percentage of Calcium Oxide (CaO) in PFA cement caused the temperature not increased to the highest peak when the hydration happened.

Based on the particle size diagram in Figure 2, it can be concluded that PFA particles are smaller than the OPC particles. For OPC and PFA, the percentages going through a 10μm sieve are 30.2% and 43.2%, respectively. The particles vary from 10 μm to 35 μm in total dimension, with the smallest being less than this. Class F-PFA in particular includes calcium from 1 to 12% of the silicon and alumina material, in the form of calcium hydrate, calcium sulphate and glass.

![Figure 2. Particle size analysis of OPC and PFA](image)
The C-S-H gel was found in the early stage of cement paste production to occupy around half of the volume. C-S-H sets the pore cement into a solid gel mixture. The quick hydrating mechanism somehow causes morphologies to develop tiny internal pore spaces that do not engage with the C-S-H as shown in Figure 3(a). The temperature indication of OPC, PFAC, KFC, and KFPC have been displayed in the Figure 4. As the hydration process happened, the maximum temperature of 31.6°C is reached at 16.25 hours and then drops to 25.5°C. The combination of 25% Pulverised Fuel Ash Concrete in PFAC resulted in a 30.1°C maximum mixing temperature of 19.25 hours. As fibre was added, the mixture begins to set at a temperature of 30.8°C. During a mixing time of PFA and kenaf, the lowest temperature was 29.6°C, where the KFPC was reported. Previously, the addition of fiber in PFA concrete lower the cracks in the PFA and KFPC concrete sample [9]. This indicates that due to the reduction in temperature in the hydration process then less cracking occurs when the load is applied.

![SEM images of the microstructure of OPC and PFAC](image)

**Figure 3.** SEM images of the microstructure of OPC and PFAC

The PFA and fibre were initiated a longer duration to bind, hence decrease the temperature, PFA to form a dense and compact matrix at a lower temperature. Fly Ash has been stated to have a little reaction in the hydration process [25]. The compressive strength of PFA was stated by Azzmi, N.M [14] indicate the compressive strength of PFA concrete was higher than OPC concrete in 56 days means it takes a longer time to enhance the strength, however it increases gradually. The greater compressive strength results demonstrated the ability of concrete to withstand a force caused by its solid matter. The hydration phase was improved by partial replacement of PFA cement as a filler in the pore structure as shown in figure 3 (b). The resistance characteristics from water penetration and other chemical attacks make it durable by providing more calcium silicates hydrate (CSH) in material composition.
4.0 Conclusion

This study shows the effect of the chemical composition of PFA cement that improves concrete to dense compared to normal concrete. The later reaction of the pozzolanic cement, has been described as a special additional concrete cementing material that enhanced the strength of concrete. The results obtained and the findings made in this study indicate that the partial substitution by pulverised fuel ash is beneficial, particularly for mass concrete where thermal cracking is of vital importance due to excessive heat increase. The current analysis was carried out with a 25% ash replacement, KFPC to minimize temperature in the hydration phase compared to normal concrete.

In general, other replacement values of PFA cement need to be considered in further study to achieve higher performance of concrete in the transition of cement paste to concrete in the hydration phase. The hydration mechanisms play important role in the mechanical properties of concrete.

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