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Assessing the Strength Characteristics of Cement Mortar using Eggshell Powder and Kenaf Fiber

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Abstract

The construction industry is increasingly using industrial waste in building applications like concrete, mortar, and brick manufacturing due to sustainability concerns and environmental concerns. Eggshell powder (ESP) and kenaf fiber (KF) can be used as fine aggregates and cement in mortar manufacturing due to their availability, chemical composition, and light weight. ESP is a good filler or substitute in many composites, while KF is a good additive in cement due to its affordability, renewability, and recyclability. However, their potential to produce cement mortar has not been extensively investigated. This study investigates the strength of mortar made using ESP and KF and determines the ideal proportion of ESP and KF in a mortar. The study involved samples using different proportions of KF as an additive in cement (0.6%, 1.2%, and 1.8%) and ESP as a replacement in fine aggregate (5%, 10%, and 15%). The results showed that the standard cement mortar with a concrete strength of 20.447 N/mm^2 had the best compressive strength and high density 2161 kg/m^3 of mortar at 28 days. However, the sample with KF of 0.6% and ESP of 5% had the best performance. Lower the percentage use of the kenaf fiber in the mixture to obtain an optimum proportion with better results.

1. Introduction

Cement-based materials (CBMs) are in great demand due to the increasing number of building requirements [1]. CBMs consist of three main components: fine aggregates, cement, and water. The production of cement consumes a lot of energy and produces a lot of carbon dioxide (CO_2) [2]. Scientists arenow working to develop suitable alternatives for cement and natural aggregates to encourage environmentally friendly construction [3]. Previous studies investigated multiple alternatives for conventional fine aggregate and cement, and it has been suggested that recycling waste materials as replacements for aggregates and cement in CBMs could help reduce the environmental problems associatedwith open waste disposal [4].

Among the waste materials produced, chicken eggshell is one that has been pointed out worldwide as one of the environmental challenges, particularly in countries where the egg product industry is well developed [5]. According to [6], many different kinds of studies used eggshell components for multiple uses. Eggshell is a suitable source of filler or replacement in many composites due to its availability, chemical composition, and lightweight. Eggshell waste materials can be used instead of natural lime in buildings to reduce cement use while keeping natural lime. The eggshell powder (ESP) is a biomaterial having a chemical makeup similar to limestone. Using eggshell powder instead of natural lime to replace cement in CBMs can be useful, such as minimizing the use of cement, conserving natural lime and benefited from waste material.

Cementitious composites, such as grout, mortar, and concrete, are the most widely used building materials for a wide range of infrastructure projects around the world that require high ductilities and energy absorption capacity, such as bridge decks, highway pavement, and industrial building floors. Cementitious composites, on the other hand, have low tensile strength, weak ductility, limited cracking resistance, and little energy absorption [7]. One way of improving the cementitious composite is by introducing fibers. Kenaf Fibers (KF) is currently gaining popularity due to the increasing usage of natural fibers and the need to meet their demand for composites, resulting in the development of kenaf as an industrial crop worldwide[8]. Despite the numerous advantages of using KF, they have a high water and moisture absorption capacity, which must be addressed before they can be used in cement-based composites. KF is not widely used for large-scale structural applications due to the lack of understanding and research related to its effect on the performance of cement-based composites. As a result, the purpose of this study is to investigate the current literature on the effects of KF and ESP on the properties.

1.1 Objectives

There are two objectives of this research which include:

- To investigate the strength of mortar made using eggshell powder and kenaf fiber.
- To determine the ideal proportion of eggshell powder and kenaf fiber in a mortar.

2. Materials and Methods

The goal of this study was to generate concepts that would serve as an outline for carrying out the project's research. There are numerous sources from which we can obtain ideas that was be used as reference material for this research, including journals, newspapers, electronic media, and others. This study was also look at the application and characteristics of ESP and KF waste based on previous studies. The tests that was used in this study are compressive strength, water absorption and density that was be performed according to the standard procedures. In addition, the properties of cement, aggregate, and water are covered. ESP and KF are excellent materials for replacement and addition for traditional concrete mortar because they are affordability and less expensive. By minimizing waste generation and encouraging the use of sustainable materials, the use of these materials in the manufacturing of concrete can help to reduce the environmental effect of building. The material that will be used in this thesis is critical to achieving the expected outcome. The materials used in this study will be Ordinary Portland Cement (OPC), fine aggregates, water, KF as addition in cement and ESP as replacement in fine aggregate. This chapter also explains how to prepare the sample.

2.1 Kenaf Fiber

In this study, KF were obtained and purchased from Rahamatullah Sdn. Bhd from Petani, Kedah, Malaysia. For kenaf to be mixed with other materials, it must first pass through raw kenaf fibers, which are treated alkaline by soaking the fibers in a 6% sodium hydroxide solution (NaOH) for 1 hour at room temperature [9]. The main obstacles to using kenaf fiber as reinforcement in composites are its high water of absorption capacity, low durability, and poor fiber-matrix adhesion. The high moisture absorption of natural fibers reduces the overall mechanical performance of the composite. Moisture absorption and lack of interfacial bonding make kenaf fiber composites less effective in transferring stress and have lower durability [10]. Surface pre-treatment with chemical or physical modification has been established as an efficient way to reduce the water absorption of these fibers and increase the bonding between the fiber surface and the mortar matrix [11]. Figure 1 below shows the sample of KF.

Fig 1. *Kenaf Fiber*

2.2 Eggshell Powder

In this study, eggshells were collected by self-collection from a bakery factory in Kulai, Johor. Eggshell primarily consists of multiple layers of calcium carbonate ($CaCO_3$) of the compound [12]. The eggshell that be used for this study are samples that pass through the 5 mm sieve for the cement mortar mixing. Figure 2 shows the ESP that be used for this study.

Fig 2. *Eggshell Powder*

2.3 Compressive Test

Compressive strength is the most important mechanical attribute to determines the performance of the cement mortar. This test is conducted to determine the compressive limit of cube samples. The testing followed the procedure outlined in BS 1881 Part 116:1983: The Standard for Testing concrete - Method for determination of compressive strength of concrete cubes. The compression tests are conducted after 7 days, and 28 days of curing. This test aims to determine the ability of concrete to withstands crushing loads and is measured in Mega Pascal (MPa) which indicates the normal strength of concrete. Figure 3 shows the compression test machine at UTHM concrete laboratory. Following the curing process, the cube samples will be recording their weight and placing them in the compression test machine. Before put the sample, clean the surface of the machine. Each samples's highest load reading is recorded, and the average reading is calculated as a percentage.

Fig 3. *Compression test machine*

2.4 Water Absorption

A water absorption test is used to determine the percentage of water absorption of a cement mortar sample. The test is performed after the concrete block samples have been cured for 7 and 28 days. It will be carried out in accordance with the standard BS 1881: Part 122: 1983 (Method of determining water absorption). After the concrete block has been set, the weight is measured, and the reading recorded as the initial mass. It will then be placed in a container and soaked in distilled water at a temperature of 32°C. Figure 4 shows the curing tank that be used for this study. After soaking, remove the block from the water and let the water that remained to drain for a few minutes. The weight of the specimen was measured and recorded as the value of the wet mass of the concrete block. Each specimen's water absorption % was calculated. Figure 4 shown the curing tank that will be put the samples.

Fig 4. *Curing tank of samples*

2.5 Density

To determine the density of samples containing KF and ESP are performed on them after 7 and 28 days of curing. BS 1881 Part 114-1983 has been used for this density testing to measure the density of mortar. Each sample of cement mortar is weighed to determine its mass and the data was recorded. The following formula is used to get the value of the sample's density, which is then calculated. The density of cured cement mortar is kilogram per cubic meter (kg/m^3).

3. Results and Discussions

The result is obtained from laboratory tests and presented as graphs and data. The data and results obtained was help to achieve the study's objectives. Mixture samples of KF and ESP were determined with different mixing ratios to achieve the objectives of this study. The results from the sieve analysis test, compressivestrength test, water absorption test, and density of concrete were used in this study. All collected data was be provided in graphs and tables for a better understanding of data analysis.

3.1 Compressive Strength Test

Table 1 *Result of compressive strength tests*

Percentages of Kenaf Fiber in Cement and Eggshell Powder in Fine Aggregate (%)		Average Strength of Mortar Cube (N/mm^2)	
Kenaf Fiber	Eggshell Powder	7 days	28 days
Control	Control	11.791	20.447
0.6%	5%	14.899	13.780
1.2%	10%	10.224	8.776
1.8%	15%	5.239	7.081

The test was performed according to the procedure outlined in BS 1881 Part 116:1983: The Standard for Testing concrete - Method for determination of compressive strength of concrete cubes. The results of compressive strength tests with different percentages of KF in cement and ESP in fine aggregate at 7 and 28 days are shown in Table 1. The result was obtained by taking the average of three samples determined on the Compression Strength Test Machine.

Referring to BS EN 1015-11 it says that normal Portland cement mortar achieves a minimum compressive strength of around 10 MPa at 7 days and the minimum compressive strength of cement mortar for 28 days is around 20 MPa. Based on the Table 1 the cement mortar achieved the minimum compressive strength in 7 days and obtain the required characteristic compressive strength in 28 days.

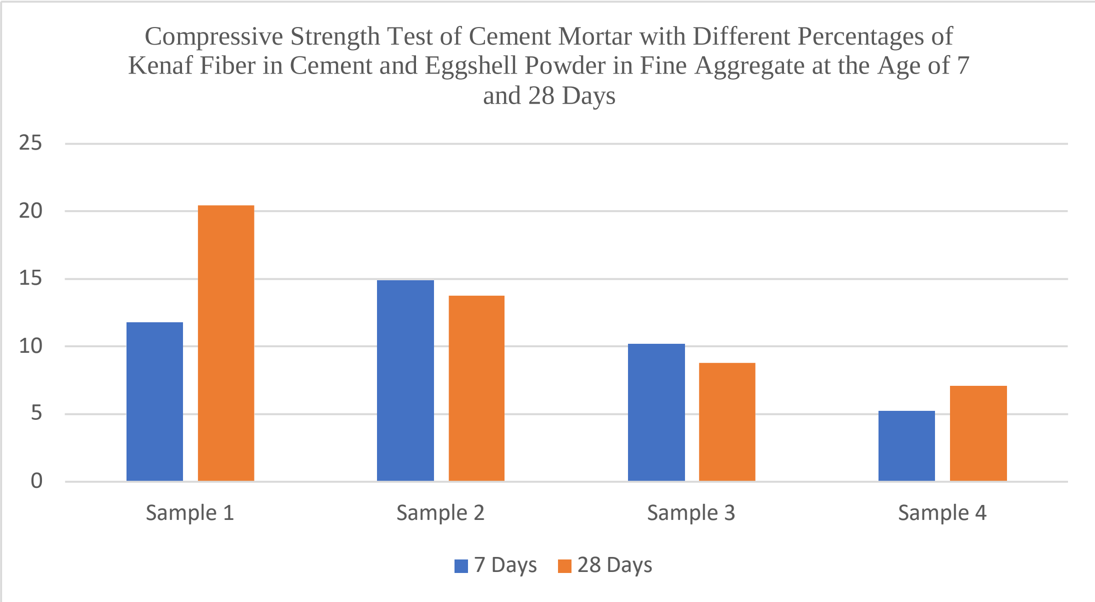

Fig. 5 *Graph of compressive strength test of cement mortar with different percentages of kenaf fiber on cement and eggshell powder in fine aggregate at the age of 7 and 28 days*

Figure 5 shows that at 7 days, the increase in KF and decreased ESP in sample 2 shows an increase in strength but a decrease in the following percentage. At 28 days, the graph shows that strength decreases as the percentage of KF in cement and ESP in fine aggregate increases from sample 1 to sample 4. The compressive strength of cement mortar samples with KF additions of 0.6% and ESP reductions of 5% had greater values thanmortar with other percentages. This shows that ESP reduction in cement mortar cannot be used in large quantities while kenaf fiber as an additive in cement mortar cannot be used in large quantities. As for kenaf fiber, it is a good material to strengthen the material but it can lead to moisture absorption which makes cement not absorb much water because of kenaf fiber and makes the material to be low strength [13]. The main reason for this contrast is the water content in the mixture. Adding KF with higher content and longer length made the mixture drier and resulted in difficulties in the placement, vibration, and compaction of the mixture, thus reducing its strength [14].

3.2 Water Absorption Test

The water absorption test was conducted in the following BS 1881-122: 1983 - Water Absorption Method Determination Procedure. The water absorption test results with different percentages of KF in cement and ESP in fine aggregate at 7 and 28 days are presented in Table 2, and the water absorption test graph is shown in Figure 6. The result is achieved by taking the average value of three cube samples that have been placed in an oven at a temperature of 105°C for 24 hours.

Table 2 *Results of water absorption tests*

Percentages of Kenaf Fiber in Cement and Eggshell Powder in Fine Aggregate (%)		Average Percentage of Water Absorption (%)	
Kenaf Fiber	Eggshell Powder	7 Days	28 Days
Control	Control	4.156	4.214
0.6%	5%	5.749	7.409
1.2%	10%	8.719	10.669
1.8%	15%	10.847	12.158

Based on the Table 2, the cement mortar using of 1.8 % KF in cement and 15% ESP in fine aggregate has the highest percentage of water absorption compare to the other results. This may dueto the added of KF in the mixing of the mortar. According to [14], although KF can be used as addition to cement in cement mortar, the amount of water in the mixture was be reduced, resulting in a decrease in workability. When ESP is added, the water absorption is reduced compared to the control sample. Because ESP is finer than sand and produces betterparticle assembly, this may be the main factor causing the decrease in water absorption [15]. With this, both materials impact the increased percentage of water absorption in cement mortar mixing.

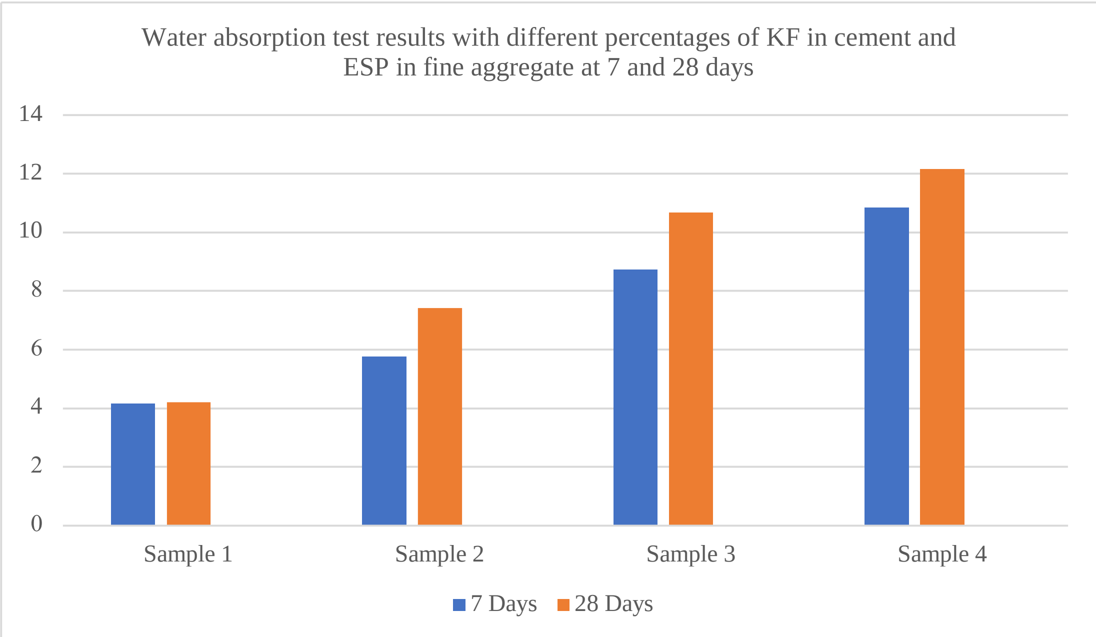

Fig. 6 *Water absorption test results with different percentages of KF in cement and ESP in fine aggregate at 7 and 28 days.*

Figure 6 shows the increase in water absorption of the KF added in cement and the reduction of ESP in fine aggregate. This is because the added KF has a high-water absorption rate. Because of the extremely high-water absorption of KF, the water required for one ratio is insufficient for making a mixing mixture. However, the ESP which is used as a substitute for fine aggregate, does not absorb water unlike KF absorption. As a result, water is placed in a circumstance where it is more likely to be absorbed more by KF. The longer the duration of the curing process, the greater the water absorption. According to [16], a good mortar mix has absorption well below 10% by mass. Sample 3 of 28 days and both samples 4 of 7 days and 28 days fail to achieve an ideal mortar mixture, which might lead to a reduction in cement mortar strength.

3.3 Density

BS 1881 Part 114-1983 was used for the density test, intended to measure the density of mortar. The density of cement mortar is an important aspect in determining its physical and mechanical performance. The density of each sample was calculated by using the formula density, mass per unit volume. The density of the cement mortar was calculated using the average of three cubes aged 7 and 28 days.

Table 3 *Result of density of cement mortar with different average percentages of KF added in cement and reduced ESP in fine aggregate at 7 and 28 days of age*

Percentage of Kenaf Fiber in Cement and Eggshell Powder in Fine Aggregate (%)		7 Days	28 Days
Kenaf Fiber	**Eggshell Powder**	**Average Density (kg/m^3)**	**Average Density (kg/m^3)**
Control	Control	2127	2161
0.6%	5%	2106	2084
1.2%	10%	2015	1981
1.8%	15%	1919	1946

Table 3 shows the data for the density test that has been conducted at 7 and 28 days of curing. For each cement mortar sample, the readings were recorded and graphs have been plotted to differentiate the results with each sample clearly. Based on the data above, it shows that the density of each sample varies with different percentages of KF added in cement and ESP reduction in fine aggregate in cement mortar.

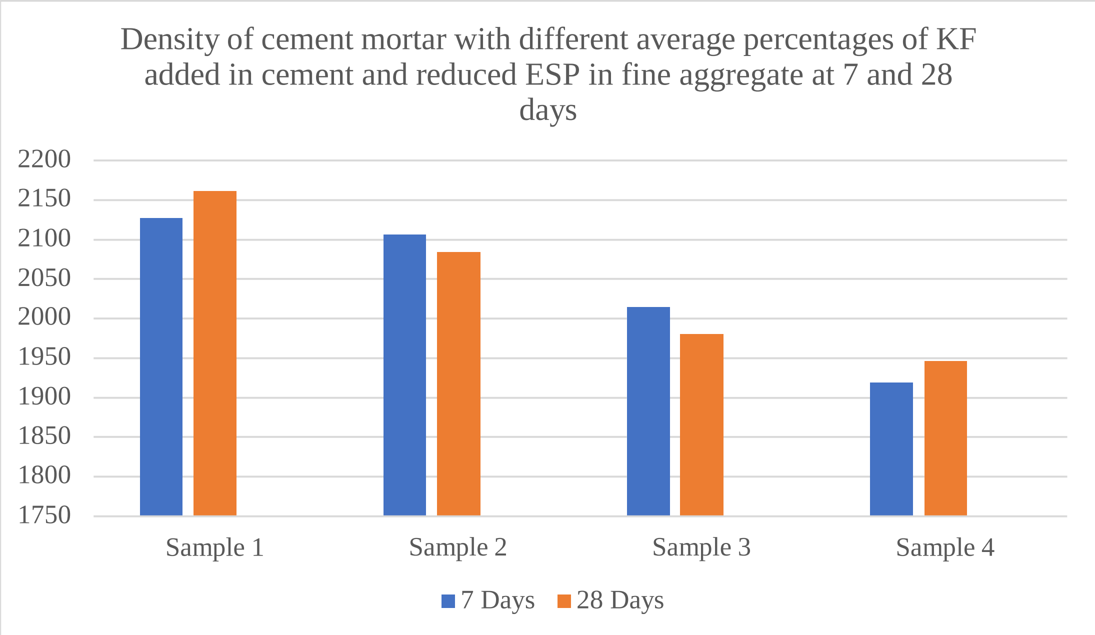

Fig. 7 *Density of cement mortar at 7 days and 28 days with different average percentages of KF added in cement and reduced ESP in fine aggregate*

The graph in Figure 7 shows that the density value for sample data 1 to 4 decreases, with the lowest value is 1919 kg/m^3 at 7 days. The density data shows a decrease in value from sample 1 to sample 4, with the lowest value at 28 days being 1946 kg/m^3. According to the findings, the maximum density was recorded at 7 and 28 days, which was 2127 kg/m^{3}and 2161 kg/m^{3}in sample 1. While the lowest density was obtained at 7 and 28 days in sample 4, with values of 1919 kg/m^{3}and kg/m^3, each. According to the results, the higher the sample density, the higher the compressive strength of the cement mortar. Based on BS 1881 Part 114-1983, the cementmortar classified into three types: low density mortar (1600 to 1800 kg/m^3), normal density mortar (1900 to 2100 kg/m^3), and high density of mortar (2100 to 2400 kg/m^3). Thus, all of the cement mortar samples are considered normal density mortar except for sample 1 at 28 days, which has a high density of mortar. The difference in density between each sample is because KF is very lightweight and ESP contains $CaCO_3$, which is a relatively lightweight compound.

4. Conclusion

The first objective of this study is to investigate the strength of mortar made using eggshell powder and kenaf fiber. Based on the results, the standard cement mortar with a concrete strength of 20.447 N/mm^2 has the best compressive strength and a high density of mortar of 2161 kg/m^3 when compared to the KF added in cement and ESP reduced in fine aggregate, but the sample with KF of 0.6% and ESP of 5% had the best performance when compared to others. The strength of cement mortar is likely to be decreased because too much eggshell reduction and kenaf fiber are used as materials with extremely high of water absorption. This reduces the strength of the cement mortar. However, because the standard compressive strength of brick used in buildings ranges from around 3.5 N/mm^2 to 40 N/mm^2, this study can be applied in the construction area.

For the second objective, this study aimed to determine the ideal proportion of eggshell powder and kenaf fiber in a mortar. In some past studies, it was observed that the majority of ESP percentages used were in the range of 5% to 30%, while KF was used in the range of 0.5% to 2%. The mix design in this study was calculated using the mortar density method to obtain the actual amount of cement, fine aggregate, water, ESP, and KF required for 6 samples in each ratio. Cement mortar with KF 0.6% and ESP 5% is the ideal ratio for this study in terms of compressive strength, water absorption, and density, and it is not compared with standard cement mortar.

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