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Initial and Final Setting Time Determination of 3D Printing Mortar with Kenaf Powder Addition

Ismail. Amira[1], Ibrahim.M[2*], Abdullah. Radziah[3]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[2]Advanced Manufacturing and Materials Center, Institute of Integrated Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[3]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: The construction industry is likely to undergo significant alterations from conventional method to the potentially disruptive technologies such as 3D concrete printing (3DCP). The use of the natural fibers in the mortar for 3DCP applications will increase the environmental awareness, allowing for further research for new sustainable materials in construction industry. The contribution of this study to identify the effects of kenaf powder as a natural fiber on setting time.as a first stage for determination on the fresh properties of the 3D printing mortar. The goals of this research is to create a good mix design that passes the experimental works and be able to be used on 3DCP.This experimental works is an important parameter to guarantee that mixes harden at appropriate time to ensure the bonding between each layer of the 3D printing mortar. Ordinary Portland cement (OPC), dust sand, organic plasticizer and polymer were used as a part of 3D printing mortar. Vicat apparatus in accordance to ASTM standard is used as an apparatus to determine the initial and final setting time. In general, the addition of the kenaf powder with 30%, 40% and 50% effect the both initial and final setting time. Kenaf powder with 40% weight by cement and 325g water content was chosen as an acceptable mixture to be applied on 3DCP because it required the appropriate time for harden enough to stack layer by layer without changing its forms and passed the standard setting time of 600 minutes.

Keywords: Setting Time, Bio-Composite, Natural Fibers, Kenaf Powder

1. Introduction

Bio-composites material is a new material that have been used by many researchers as a sustainable and renewable application in construction and automotive field. There are plenty types of bio-composite that are commonly used, including sisal, banana, cotton, flax straw, jute, bamboo, and coconut, which

Corresponding author: ibrahim@uthm.edu.my

all have their own advantages in terms of strength and as reinforcement in 3d construction [1]. Natural fibers resulting high strength concrete which the addition of the bio-composite in the cement mixture can be categorized as a brittle by a post-peak behavior which generally can maintain and prevent the tensile cracking on concrete structures [2]. The use of natural fibers instead of synthetic fibers can improve the environment and can easily disposed without harming the ecosystem [3].

Kenaf, known as Hibiscus cannabinus L., is a natural fiber that is well-known for its usage reinforcement in polymer matrix composites (PMC) [4][5]. Kenaf has variety of usage, including paper products, construction materials, animal feeds and also as an absorbent materials and suitable to subtitutes synthetic fibers [6]. Kenaf fiber is widely used as a building materials to improve the sustainability. Several researcher conducted research on kenaf fiber reinforced concrete [6][7][8][9]. However, there is no source or prior researcher that has conducted a study on the usage of kenaf as a natural fiber to be used in 3D concrete printing. It is a new study that highlights the usage of kenaf as an admixture in cementitious material use in cement-based 3D printing.

Cement-based material in 3D printing is a new innovation in construction industry which this method can be used to develop the complex and freeform geometrical structures without having a formwork and give a huge advantage than a conventional method [10]. Since the viscosity of the cement-based material vary than often used in conventional method, the material selection for the construction of the cement-based material for 3D printing is vital to the structures to be developed. The mortar used for 3D printing must be workable, so that when the mortar pumped out from the nozzle, the mixture comes out smoothly and stays in shape [11]. The main feature of the mortar-based material for 3D printing is that the fresh mortar does not harden too quickly in order to maintain the bond strength between each layer of the 3D mortar [11].

One of the most crucial criteria in the printing process is the open time. The open time is related to the setting time. Setting time has traditionally been used as a fundamental test for transportation, concrete placement, and compaction [12]. L.J Vicat proposed the setting time measurement approach in the nineteenth century [13]. Several research has study regarding to the setting time of natural fiber composites. A. Varshoee et al. [14] studied the cement bagasse fiber composite of sugar cane with 4% and 10% by weight of the cement. The used of the calcium chloride as accelerator in the cement increase the speed of hydration process. P. Murthi et al. [15] studied the setting time of high performance fiber reinforced concrete (HPFRC) by using blended banana fiber with a various percentage. Its showed the presence of the fiber content in the mixes increased the setting time level of the HPFRC which effect the reduction in hydration process. When the final setting time of the cement paste reaches 10 hours (600 minutes), the mixture is known to have failed. There is no source or prior studies on the use of kenaf as an admixture in the cement matrix for cement-based 3D printing. Thus, the current research paper aims to investigate the setting time of kenaf powder admixtures to the 3D printing mortar as a potential material in 3D printing in building industry.

2. Materials and Methods

2.1 Materials

The bio-composite binders are formed with cement, dust sand, kenaf powder, polymer and organic plasticizer. The cement used is Ordinary Portland Cement (CEM I 42.5N). The used of dust sand with particle size of 0.5mm and kenaf powder with size passing through 150µm (**Figure *1***). Kenaf powder is used as an admixture in the 3D printing mortar. The chemical composition and properties of the cement is given in Table 1. The specific gravity of kenaf powder 1.07. The used of organic plasticizer and polymer in the cementitious mixture is used to adjust the workability of the mixture [16]. Fifteen samples with 30%, 40% and 50% of kenaf powder by weight of cement and different weight of water is used to determine the effect of the setting time of the mixture as shown in Table 2. The mixing process was as follow: the dry material (cement, kenaf, and dust sand) were mixed for 1 min and the liquid

material (water, organic plasticizer and polymer) were mixed for 5 min to ensure the mixture is properly mixed.

Figure 1: Kenaf powder with particle size that passing through 150µm

Table 1: Chemical Composition of OPC Type I 42.5N [17]

Ordinary Portland Cement Type I (42.5N)	**Chemical Composition**
SiO_2	21.41
Al_2O_3	4.88
Fe_2O_3	3.82
CaO	63.69
SO_3	2.36
MgO	1.56
Na_2O	0.47
K_2O	0.65
Compounds	
C_3S	51.59
C_2S	22.48
C_3A	6.47
C_4AF	11.62

2.2 Methods

The setting time of the cementitious paste mixture were determined by Vicat apparatus accordance to ASTM C191- 04 [18] (Figure 2). The testing performed on a fresh mortar mixture with addition of variance weight of kenaf powder admixtures, which obtained by sieving the kenaf powder through sieve No. 100 to achieved 0.15mm of kenaf powder. Figure 3 shows a cementitious paste for setting time experimental. The initial setting time is determined by a vicat needle with 1.13mm diameter and measured it until the time when needle fails to penetrate 5.0 ± 0.5mm from bottom of the moulds. The final setting time is determined by circular needle when its fails to make an impression on the surface of the mixture.

Figure 2: Vicat apparatus experiment for setting time

Figure 3: The 3D printing mortar for setting time experimental

Table 2: Mixtures Proportions of Cementitious Paste

No	Materials	Quantity
1.	Cement	125g
2.	Dust Sand	87.5g, 75g, 62.5g
3.	Kenaf Powder	30%, 40%, 50%
4.	Organic Plasticizer	25g
5.	Polymer	25g
6.	Water	275g, 300g, 325g, 350g, 375g

3. Results and Discussion

3.1 Effects of Kenaf Powder On Setting Time

The results as provided in Table 3 clearly indicates the addition of kenaf powder into the 3D printing mortar causes significant in both initial and final setting times, with the setting times increases as the addition of kenaf powder increases. From the observation made by A. Varshoee et. al [14] on the

research of cement bagasse fiber composites showed that the using of the fiber treatment shortened the hydration process and increased the setting time of the cement. Figure 4 summarized the results and shows the relationship between kenaf powder content and water content on setting times.

Table 3: Results of initial and final setting time of cementitious paste

Trial No	Initial Setting Time	Final Setting Time
K30W275	510 min	540 min
K30W300	570 min	600 min
K30W325	684 min	720 min
K30W350	870 min	900 min
K30W375	996 min	1020 min
K40W275	200 min	270 min
K40W300	260 min	350 min
K40W325	460 min	552 min
K40W350	1020 min	1140 min
K40W375	1320 min	1440 min
K50W275	168 min	180 min
K50W300	186 min	210 min
K50W325	288 min	300 min
K50W350	384 min	402 min
K50W375	402 min	420 min

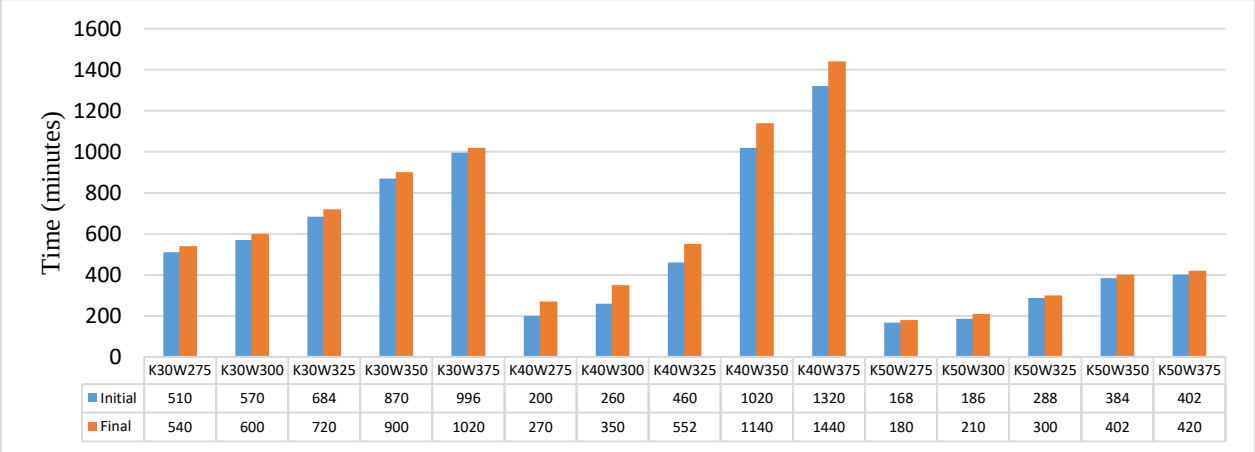

Figure 4: Setting time of 3D printing mortar

Figure 4 shows a results of fifteen samples of kenaf powder addition with a variance of water content in each mixtures. The relationship of water addition in the 3D printing mortar mixtures in both initial and final setting times it also important to observe, where the setting times increase at higher water content. The addition of water cement ratio leads to increase in both initial and final setting time [19]. Among the all mixes, 3D mortar contains 40% of kenaf powder with 375g of water content (K40W375) exhibited the highest retarding effects. This increase in initial setting time is 7.86 times higher when compared with initial setting time for K50W275. When compared between two mixes, it can be determined that the used of high volume of kenaf powder and a little water results in denser mixture, which reduces the time in both initial and final setting times. The denser the mixture is incompatible for use in the 3D machine because the characteristics of the mixture must be flowable enough so that the 3D printing mortar flows smoothly and can retains the shapes when its be extrudes. This statements supported by Z. Malaeb et. al [20], where the mix design aims for 3D concrete printing

are to maximize the flowability of the mixes so that the mixes can keeps their forms and layers and should set quickly enough but no so fast enough to assure the bonding of each layers. According to T. T. Le at al.,[21] initial and final setting time is not very suitable to be used as an experimental method for the open time which because it does not assist in changing the workability of the time with the 3D printing mortar. This statement supported by G. Ma et al., [22] where the setting time is not applicable method to evaluate the printing abilities due to the printing materials in most cases required stiffness within ten minutes. Furthermore, the texture of the 3D printing mortar must be flowable enough to be used in the machine so that when the 3D mortar extrudes from the nozzle, the mortar flows smoothly without air voids and stuck in the nozzle.

4. Conclusion

Based on the experimental conducted with three different amount of kenaf powder, it can be seen that there is a significant result that effects the setting time of the 3D printing mortar. The addition of kenaf powder with a various percentage and water content to the mixture effects the time taken of the mixture to completely lose its plasticity. The higher the amount of kenaf powder added into the mixture, the higher the time taken of the mixture to start harden. In general, when applying to 3DCP, the mix design is a critical aspect to be considered. The ideal mixture for application to the 3DCP must have a good texture so that it flows smoothly without any air trapped when extrudes. Furthermore, the mixture must harden at sufficient rate, so that the structure does not lose its shapes when developed layer by layer. Based on standard setting time of OPC, only ten from a fifteen sample pass the experiments. Five sample of the 3D printing mortar exceeds 600 minutes (10 hours) of the setting time. In conclusion, the most suitable sample with a good mix design to be applied to the 3DCP is K40W325 which the use of kenaf powder is 40% and water content with 325g.

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