

# POTENTIAL OF NATURAL AND SYNTHETIC FIBRES ON FLEXURAL PERFORMANCE OF FOAMCRETE MORTAR

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## Graphical abstract



## Abstract

This research investigates the potential of natural and synthetic fibres on flexural strength of foamcrete mortar. The are 7 different types of fibres had been used such as pulverized fuel ash, wood ash, silica fume, palm oil fuel ash, polypropylene fibre, coconut fibre and steel fibre. These natural and synthetic additives have different abilities that contribute positive outcomes to the properties of foamcrete mortar. Pozzolanic materials and fibres were used as additives to be included with control foamcrete mortar mixtures in order to enhance its flexural properties. From the overall analysis, it has been confirmed that coir fibre recorded the highest flexural strength in 7 days compared to other additives and the control sample. Coir fibre of 0.4% reached highest strength in 180 days without allowing other additives to overcome its overall flexural strength. It should be pointed out that, the more the addition of fibres in the base mix, the higher the strength obtained due to its low cellulose content.

*Keywords:* Foamcrete, mortar, flexural strength, concrete, fibre

## Abstrak

Kajian ini mengkaji potensi penggunaan serat semulajadi dan sintetik ke atas kekuatan lentur konkrit berbusa. Terdapat 7 jenis gentian yang digunakan seperti abu lumat bahan api, abu kayu, wasap silika, abu bahan api minyak sawit, serat polypropylene, serat kelapa dan gentian keluli. Bahan-bahan serat ini mempunyai kebolehan yang berbeza yang menyumbang hasil positif kepada sifat-sifat konkrit berbusa. Bahan pozzolanik dan serat digunakan sebagai bahan tambah untuk dikaitkan dengan campuran konkrit berbusa biasa untuk memperbaiki sifat mekanikal. Daripada analysis keseluruhan yang dibuat, dapat dinyatakan bahawa serat sabut mencatatkan kekuatan lenturan yang paling tinggi dalam 7 hari berbanding bahan tambahan lain dan sampel kawalan. Serat sabut sebanyak 0.4% mencapai kekuatan lenturan yang paling tinggi dalam 180 hari tanpa membenarkan tambahan lain untuk mengatasi kekuatannya. Semakin tinggi jumlah penambahan serat, semakin tinggi kekuatan lenturan yang diperolehi atas faktor kandungan selulosa yang rendah.

*Kata kunci:* Konkrit berbusa, mortar, kekuatan lenturan, konkrit, gentian

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## 1.0 INTRODUCTION

It has been observed that the high density of the foamcrete mortar produces high flexural strength, while low density gains very low strength as observed in the compressive strength tests [1]. As expected, the density of the foamcrete mortar influenced by its

porosity had significant effects on the flexural strength of the foamcrete mortar [2]. The flexural strength of foamcrete mortar is directly proportional to its compressive strength because the same factors that affect the compressive strength are expected to influence the flexural strength as well. Air voids, pores and matrix which attribute to the microstructure

normally will influence strength which is in relation to the density [3].

Flexural strength and splitting tensile force is similar to compressive strength when undergo tests at the age of testing. The ratio of flexural strength of foamcrete mortar to its compressive strength is in the range of 0.06-0.10. The decreasing densities and increase in water cement ratio will reduce the ratio of flexural to compressive strength. The ratio is varies from 0.22- 0.27. Both compressive strength and flexural strength show similar mechanical properties and behavior [4].

The strength will be differed when added with other additives. Natural and synthetic fiber will be able to enhance the flexural strength. Higher fibers inclusion (polypropylene and Kenaf fibers) leads to high flexural strength [5]. Fibers act as bridging component in foamcrete mortar when cracks were formed [6, 7]. Apart from fibers, fly ash also contributes to the tensile strength of foamcrete mortar [8]. The fineness of fly ash will influence the tensile strength of a concrete because it get the filling rate of concrete increases [9]. A uniform pore distribution occurs in a more dense and impermeable structure [10].

## 2.0 MATERIALS

Natural fibers have been used to reinforce inorganic materials for thousands of years. The compressive strength decreased gradually due to the increase of fiber volume percentage in conventional concrete [11]. Lower density of foamcrete mortar caused the strength to be lower and increased volume percentage of coconut fiber also will lower the density of concrete and produces low compressive strength [12]. Strength of coir fiber can be varied in terms of their diameters, strain rate, moisture absorption, lengths and their chemical properties. Natural fibers are strongly hydrophilic materials and good moisture absorber, thus leads to a significant deterioration of its mechanical properties [13].

In this research, the additives were selected based on its behaviour and properties. These locally available ingredients can be categorized as pozzolanic materials and fibres (natural and synthetic). Those additives were incorporated into the foamcrete mortar mix as cement replacement and total fraction volume. The fibres were associated with the cement paste after the flow test and afore the density of the mortar mixture is taken; meanwhile, the pozzolanic materials were included together with cement and sand before a flow test was performed. These additives are pulverized fuel ash, wood ash, silica fume, palm oil fuel ash, polypropylene fibre, coconut fibre and steel fibre. These additives have different properties and abilities which contribute positive outcomes to the overall properties of foamcrete mortar [14].

## 3.0 FLEXURAL STRENGTH TEST SETUP

Splitting tensile is a basic and important property of concrete to determine its tensile strength. The test was conducted according to the IS: 5816-1970. The size of the foamcrete mortar sample used for the splitting tensile test is 200mm in height and 100mm in diameter. This cylindrical shaped specimen was placed horizontally between the loading surfaces of the compression machine (GOTECH GT-7001-BS300 Universal Testing Machine) as shown in Figure 1. The samples were taken out from curing process and kept inside the oven to reach a dry density. These samples were also left to cool down to attain a stable temperature. A uniform compression load was applied on the horizontally placed cylindrical sample. Finally, the sample was broken into half at the centre and considered as a concrete failure. Assuming the foamcrete mortar samples act as an elastic body, a uniform lateral tensile stress of  $f_t$  acting along the vertical plane causes the failure of the samples [15].



Figure 1 Sample being tested by the compressive machine

## 4.0 RESULTS AND DISCUSSION

High density of the foamcrete mortar produces high flexural strength, while low density gains very low strength as observed in the compressive strength tests. As expected, the density of the foamcrete mortar influenced by its porosity had significant effects on the flexural strength of the foamcrete mortar. The flexural strength of foamcrete mortar is directly proportional to its compressive strength because the same factors that affect the compressive strength are expected to influence the flexural strength as well. Air voids, pores and matrix which attribute to the microstructure normally will influence strength which is in relation to the density. In this section, the development of the flexural strength of the foamcrete mortar specimens was

observed to increase over the testing ages. However, it's clearly seen that the foamcrete mortar mix without any additives gave low strength as shown in Table 1.

**Table 1** The flexural strength of foamcrete mortar of different densities

Samples	Reference	Density (kg/m <sup>3</sup> )	Flexural Strength (N/mm <sup>2</sup> )			
			7 Days	28 Days	60 Days	180 Days
Control sample	NFC-1	700	0.27	0.34	0.40	0.40
	NFC-2	1000	0.85	0.88	0.93	1.10
	NFC-3	1400	2.01	2.17	2.56	2.84

Due to the low strength of foamcrete mortar, different types of additives were used to observe the changes in strength because these additives showed positive responses in enhancing the strength [16]. The results in Table 2 show that the different additives had different effects on the flexural strength at each age. The development of flexural strength is similar to that of the compressive strength along the age and types of additives used. The ratio of flexural strength to compressive strength at 1000kg/m<sup>3</sup> for the foamcrete mortar varied from 0.30 to 0.60

**Table 2** The effect of addition of various types of additives on the flexural strength

Samples	Dry Density (kg/m <sup>3</sup> )	Flexural Strength (N/mm <sup>2</sup> )			
		7 days	28 days	60 days	180 days
NFC-2	1000	0.85	0.88	0.93	0.96
POFA-25	1000	0.69	0.71	0.92	1.07
POFA-40	1000	0.58	0.60	0.61	0.74
PF-0.2	1000	0.84	1.11	1.19	1.25
PF-0.4	1000	0.88	1.16	1.36	1.43
SF-0.25	1000	0.83	0.88	0.90	0.98
SF-0.4	1000	1.00	1.01	1.07	1.21
SLF-10	1000	1.21	1.35	1.42	1.45
PFA-15	1000	0.87	1.32	1.37	1.55
PFA-30	1000	0.86	1.30	1.55	1.82
W5-P15	1000	0.86	1.31	1.35	1.42
W10-P15	1000	0.73	1.05	1.14	1.20
CF-0.2	1000	1.24	1.39	1.52	1.55
CF-0.4	1000	1.55	1.63	1.69	1.88

From Table 2, the inclusion of 0.4% of coir fibre (CF-0.4) recorded the highest flexural strength among the additives until 180 days. It dominated the strength at each age. A significant increase of 82%, 85%, 82% and 96% in the flexural strength of CF-0.4 had been observed in 7, 28, 60 and 180 days respectively. Coir fibre is a natural fibre that contributes more to the flexural strength and also to the compressive strength. The ratio of flexural strength to compressive strength for coir fibres (CF-0.2 and CF-0.4) showed a decrease from age to age. The fibres would not cause the sample to break apart but will react as an anti-micro crack agent which

would have prevented the cracks from widening. Since coir fibre has a higher modulus, the higher concentration of fibres need more stress. Furthermore, the flexibility of the concrete will be reduced by the inclusion of more coir fibre.

The addition of 30% of PFA in the foamcrete mortar (PFA-30) produced a 90% increment in strength compared to the control mix. Meanwhile, 15% of PFA (PFA-15) gained strength by about 61% by 180 days. From investigations, both PFA-15 and PFA-30 gained very low strength at the early stage because of the pozzolanic reactions. Large amounts of PFA will downgrade the flexural strength at the early stage and need longer time to cure and reach optimum strength [17]. PFA-15 showed enhancement in the flexural strength from the 28<sup>th</sup> day onwards but the strength of PFA-30 only started to rise up vigorously at the 60<sup>th</sup> day due to the different proportions of pozzolanic materials. In terms of the physical condition of PFA, the increase in flexural strength is attributed to the improved shear capacity between the particles of PFA and the paste phase.

PFA resulted in the highest reduction of porosity compared to the other materials and led to the refinement of pores, hence providing additional flexural strength. Besides pozzolanicity, lower foam requirement at this density also contributed to the strength development by decreasing the pore volume and providing an ease for uniform pore distribution. Similar improvement was observed by the development of strong bonding between the internal particles in concrete due to fly ash [18]. Figure 2 shows the cracks formed on the samples with two different additives after reached failure mode. Coir fibres provide better shear force than PFA by preventing the widening of cracks due to bending stress as been shown on Figure 3.



LFC sample with 30% of PFA

LFC sample with 0.4% of Coir Fiber

**Figure 2** The cracks formed on the foamcrete mortar samples with different additives



Surface of 0.4% of Coir Fiber

Surface of 30% of PFA

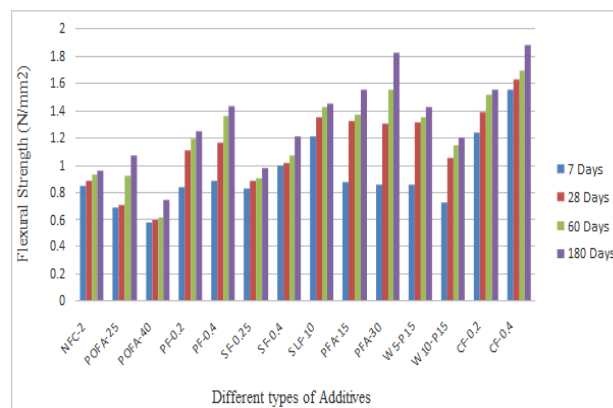
**Figure 3** The surfaces of the foamcrete mortar samples after breaking into two parts

Figure 4 shows the effect of various additives on the flexural strength of foamcrete mortar at 1000kg/m<sup>3</sup>. From the overall analysis, least flexural strength was recorded by the foamcrete mortar specimen with 40% of palm oil fuel ash. The strength of POFA-40 in 180 days is not up to the strength of the control mix in 7 days. The flexural strength at the early stage is lower and produced very little increment in strength which was only 28% from day 7 to day 180 as it had a huge cement replacement when compared to the other additives. Based on the analysis, the flexural strength will drop when the percentage of cement replacement with POFA increases. As for compressive strength, POFA-25 showed good response towards flexural strength compared to POFA-40. In 180 days, the foamcrete mortar with POFA-25 achieved 11.5% higher strength than the control mix. POFA-40 took a longer time to react with the cement during the hydration process and to reach its optimum level of strength. Since silica content gets higher when the percentage of POFA increases, the time taken for the hydration process will be longer, thus it reduces the early flexural strength of the foamcrete mortar [18]. Previous discussions have explained the microstructure formation due to the additional amount of C-S-H produced by the reactive silica in pozzolanic reactions. The additional C-S-H enhances the shear resistance and flexural strength of the foamcrete mortar specimens because the compound becomes denser and prevents the air bubbles from merging with each other. Fine POFA produced higher strength with cement replacement of 20-30% than the control mix due to its higher pozzolanic activity.

In 7 days, 10% of silica fume (SLF-10) incorporated into the foamcrete mortar showed a good start-up in flexural strength at the early stage, although it is a pozzolanic material, due to the very low cement replacement. There was a 42% increase in flexural strength by SLF-10 in 7 days compared to the control mix. The strength of the foamcrete mortar was observed to increase until the 180<sup>th</sup> day without a drop. Since the cement replacement was only about 10%, the reaction during the hydration process was completed instantly to achieve a high strength. The size and shape of the particles of the silica fume are likely to react faster with the cement and produce more C-S-H compounds during the hydration process in order to make changes in the strength of the foamcrete mortar. The pozzolanic reaction assisted the pores in becoming uniform in sizes and distribution. Since the merged bubbles were reduced, the bonding between the particles became stronger, thus increasing the shear strength of the foamcrete mortar.

Replacing cement with 5% of wood ash and 15% of PFA (W5-P15) showed that the flexural strength of the foamcrete mortar increased about 48% compared to the control mix at the 180<sup>th</sup> day and the result in 7 days shows that the flexural strength of (W5-P15) is similar with PFA-15. Increasing the percentage of wood ash in the foamcrete mortar will

reduce its strength due to low pozzolanic characteristics. 10% of wood ash with 15% of PFA (W10-P15) by cement replacement obtained lower strength than W5-P15 at all the testing ages and when compared to control mix.



**Figure 4** Effect of various additives on the flexural strength of foamcrete mortar at 1000kg/m<sup>3</sup>

As a conclusion, the flexural strength has direct linear proportional correlation with the compressive strength of the foamcrete mortar with wood ash. Analysis of the results concluded that if there is an increased level of cement replacement with wood ash, the magnitude of the flexural strength will decrease gradually upon drying. Since wood ash is less reactive than cement, it delays the setting time and reducing the bulk density of the hardened foamcrete mortar at a high proportion of wood ash due to shrinkage. Based on the strength development, it can be concluded that the reduction of the formation of micro-cracks occurs during the curing condition. Even a low amount of wood ash is used, the silica content should be sufficient to react with the calcium hydroxide from the hydration of cement. In comparison with mortar, Mortar mixed with wood ash content of 10% showed higher compressive strength in 28 days but lower flexural strength compared to the control mix [15].

An increment of 49% in the flexural strength was obtained by PF-0.4 in 180 days compared to the control mix. When compared to 0.2% of polypropylene fibres (PF-0.2), PF-0.4 showed better strength at every interval of testing. Although polypropylene fibres resulted in poor compressive strength, they slightly enhanced the flexural strength. The fibres added into the concrete resisted the bending moment load and prevented it from cracks. Fibre acts as the bridging material in concrete and prevents the formation of cracks or breaking into two parts [6]. Polypropylene fibres provide additional bonding connection for each particle to remain strong and connected due to the brittleness of its low density.

Steel fibres also produced good strength from the age of 7 days until 180 days when compared to the

control mix. It never showed any massive changes in the flexural strength along the testing ages. When comparing between SF-0.25 and SF-0.4, the high inclusion of fibres showed better compressive and flexural strength with some good additional effects because the lesser amount of fibres were not evenly spread in the whole and later led to failure of the fibre where it was unable to resist the load bearing at the very point of load. Due to the strong hold on the critical part by steel fibre, the samples never experienced cracks or broke apart. The shape of the steel fibres (hooked-end) holds the particles together and prevents cracks from widening [11]. The specimens with fibres did not fail immediately after the initial cracks appeared. This is probably due to the randomly spread fibres crossing the cracked section, which resisted the widening of cracks and separation of that section.

## 5.0 CONCLUSION

From the results obtained, it can be clearly viewed that each additive produced different level of strengths when incorporated with the foamcrete mortar. Additives used in this study have shown higher flexural strength than the sample of the control mix while other variables were kept constant. As a conclusion, the investigation proved that coir fibre gave tremendous positive response on the compressive and flexural strength of the foamcrete mortar by providing better shear stress to resist the bending moment load and act as a good reinforcing agent. Due to the pozzolanic reaction, PFA produced lower flexural strength at the early stages but the strength started to rise up enormously after 60 days and its strength in 180 days was almost similar with coir fibre. Furthermore, the strength of PFA is expected to increase if the testing ages are extended

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