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EVALUATION OF SPLITTING TENSILE STRENGTH IN PLAIN AND FIBRE-REINFORCED FOAMED MORTAR

M. A. Othuman Mydin*

School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia

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*Corresponding author
azree@usm.my

Graphical abstract

Abstract

Splitting tensile strength of concrete is normally low compared to compressive and flexural strength. Tensile force was used in the design of structural foamed mortar and to evaluate the shear resistance provided by concrete. This research focuses on the splitting tensile strength of foamed mortar incorporated with 7 different types of fibres used such as wood ash, pulverized fuel ash, silica fume, palm oil fuel ash, polypropylene fibre, coconut fibre and steel fibre. The findings show that the amount of fibres influences the enhancement level of the tensile strength. A high percentage of fibre can create a strong bonding between the particles of the foamed mortar, thus it is able to absorb energy to resist crack formation.

Keywords: Splitting tensile strength, foamed mortar, steel fibre

Abstrak

Kekuatan tegangan pemisahan untuk konkrit pada kebiasaannya adalah lebih rendah berbanding dengan kekuatan mampatan dan kekuatan lentur. Kekuatan tegangan digunakan untuk tujuan merekabentuyk struktur mortar ringan berbusa dan untuk tujuan menilai rintangan ricih bagi konkrit. Kajian ini memfokus kepada kekuatan tegangan pemisahan mortar berbusa yang dicampur dengan 7 jenis gentian seperti abu kayu, abu lumat bahan api, wasap silika, abu bahan api minyak sawit, serat polypropylene, serat kelapa dan gentian keluli. Hasil kajian menunjukkan bahawa jumlah serat mempengaruhi tahap peningkatan kekuatan tegangan mortar berbusa. Peratusan serat yang berkemampuan untuk membuat ikatan yang kuat antara zarah mortar berbusa, dan seterusnya ia mampu menyerap tenaga untuk menentang formasi keretakan dalam struktur mortar berbusa.

Kata kunci: Kekuatan tegangan pemisahan, mortar berbusa, gentian keluli

1.0 INTRODUCTION

Foamed mortar possesses lot of advantages in terms of its thermal, mechanical and fire resistance properties compared to normal strength concrete. It has faster building rate in construction industry and also reduction of dead load [1]. Since foamed mortar is light in weight, it has low handling cost and lower haulage [2]. Advantage of lower density foamed mortar is excellent thermal conductivity which can gives better insulation properties in terms of fire and sound absorption due to the cellular microstructure [3]. Thermal conductivity of a foamed mortar sample with density of 1000kg/m^3 is reported to be one-sixth of the value of common cement-sand mortar. The values of thermal conductivity are 5-30% of those recorded on normal weight concrete and the range between 0.1 W/mK and 0.7 W/mK for dry densities of 600-1600kg/m^3. Foamed mortar classified to be less efficient than denser concrete in reducing the transmission of air-borne sound [4]. Normal weight concrete tends to deflect sound waves, meanwhile foamed mortar absorbs it, and thus foamed mortar has higher sound absorption capacity. The cellular concrete does not contain significant acoustic insulation characteristics [5].

Foamed mortar mixed with 10-20% of palm oil fuel ash obtained higher splitting tensile strength at all the testing ages than the foamed mortar with 100% sand. The densification of microstructure of foamed mortar due to formation of calcium silicate hydrates (CSH) by pozzolanic activity will increase the splitting tensile strength of the prismatic and cylindrical specimens. The same reaction will be occurred in all foamed mortar incorporated with other pozzolanic materials. Silica fume needs longer time to achieve its optimum strength due to the pozzolanic reactions. Larger volume of cement replaced by silica fume will provide better response on the strength over the ages [6].

Splitting tensile force of concrete is normally low compared to compressive and flexural strength. Tensile force was used in the design of structural foamed mortar and to evaluate the shear resistance provided by concrete. Foamed mortar will show higher strength in the mixes with sand than those with fly ash [7]. This response associated to the improved shear strength between the sand. Integrating 0.2% and 0.4% of polypropylene fiber with the mix shows the flexural strength increased about 4-22% and 7-30% respectively compared to control foamed mortar [8]. It should be pointed out that 0.4% is the optimum level of adding polypropylene fiber in to foamed mortar where it can develop the flexural strength effectively and reduced the spalling effect by decreasing shrinkage cracks. Addition of polypropylene fiber at higher density is more effective than lower density. Moreover, the adding of polypropylene fiber in foamed mortar will show least improvement level at ambient temperature when compared to the high temperature [9]. The improvement of flexural strength by addition of polypropylene fibers will not give any effect on the self-compacting and the fresh concrete properties.

Apart from polypropylene fibers, high inclusion of steel fiber will give same flexural strength as other fibers [10]. Normally, low percentage of fibers added into the foamed mortar make the fibers not evenly spread in the whole which later can lead to fiber failure to resist the load taken. Steel fibers will enhance mechanical properties especially in the tensile test. The higher percentage of fiber added into foamed mortar, the better the splitting tensile strength obtained [11]. The development of flexural strength and splitting tensile strength of lightweight concrete is much better than normal weight concrete when used steel fibres [12].

2.0 MATERIALS

For this research, there are 7 types of natural and synthetic fibres were tested. All these fibres are locally obtainable ingredients which are considered as pozzolanic materials. All 7 types of fibres were added in cement paste mortar after the flow test and afore the density of the mortar mixture is taken. Afterwards the pozzolanic materials were incorporated together with cement and sand before a flow test was carried out. The 7 additives mentioned above are silica fume (Figure 1), pulverized fuel ash (Figure 2), wood ash (Figure 3), palm oil fuel ash (Figure 4), polypropylene fibre (Figure 5), coir fibre (Figure 6) and steel fibre (Figure 7). These additives have different properties and abilities which contribute positive outcomes to the overall properties of foamcrete mortar [13].

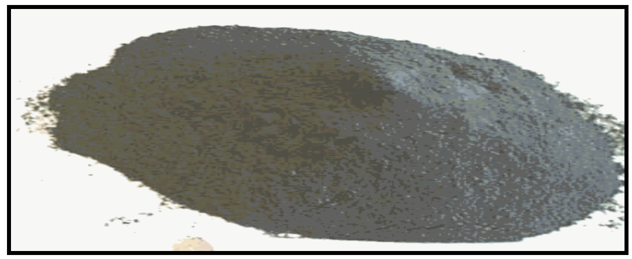

Figure 1 Silica Fume

Figure 2 Pulverised fuel ash

Figure 3 Wood ash

Figure 4 Palm oil fuel ash

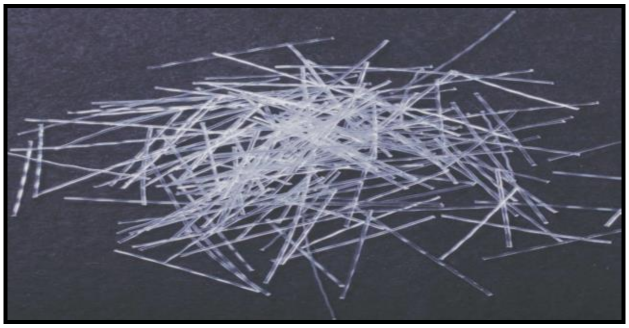

Figure 5 Polypropylene fibre

Figure 6 Coir fibre

Figure 7 Steel fibre

3.0 EXPERIMENTAL SET-UP

In order for foamed mortar to gain the strength, the curing condition is very important. A hydration process will takes place in the drying concrete during the curing condition with the aid of water. Sufficient water should be supplied as it is needed for good cohesion between the particles inside and will make the concrete stronger during the hydration process. For this study, sealed curing was chosen and applied for all mixes. The wet density of a concrete must be 1000±150kg/m^3 for sealed curing because the possibility of water loss is higher than in water curing. Water curing cannot be applied in this study because the samples below 1000kg/m^3 density will float due to water density. Besides that, if excessive water enters into the dry foamed mortar samples, it will make the pores inside expand and eventually lead to minor cracks. The dry foamed mortar specimens were placed inside a big black plastic bag and sealed to prevent water evaporation for 7, 28, 60 and 180 days. Figure 8 shows the sealed curing condition of the dried foamed mortar samples.

Figure 8 Sealed curing condition of foamed mortar samples in the lab

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 foamed 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 9. 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 [14]. Finally, the sample was broken into half at the centre and considered as a concrete failure.

Figure 8 Setup of a cylindrically shaped specimen for tensile strength test

4.0 RESULTS AND DISCUSSION

Splitting tensile strength is another element which is important in the study of the mechanical properties of foamed mortar. Tensile strength is the maximum stress that a concrete can resist while being loaded before failure. As a final part, splitting tensile strength of the foamed mortar specimens were investigated by using suitable procedures and tests in order to complete the study of the mechanical properties. Compressive, flexural and splitting tensile strengths are always interconnected in identifying the strength attribute of foamed mortar. As discussed earlier, density controls the strength of foamed mortar. Therefore, specimens with three various densities were investigated to observe the effects on the splitting tensile strength [15]. The tensile strengths changed with the densities as shown in Table 1. Due to the low density, the tensile strength of the foamed mortar was reduced at the early stage and it experienced little increment in strength along the testing ages. At a higher density, the tensile strength of the foamed mortar was higher than the control mix by 77% due to the lower content of foam which creates less air bubbles. Hence, it can be concluded that the strength of the foamed mortar specimens was influenced by its dry density

Table 1 Effect of various densities on the splitting tensile strength

Sample	Density (kg/m^3)	Splitting Tensile Strength (N/mm^2)			
		7 Days	28 Days	60 Days	180 Days
NFC-1	700	0.07	0.07	0.08	0.09
NFC-2	1000	0.21	0.22	0.25	0.25
NFC-3	1400	0.45	0.58	0.75	0.78

The density is influenced by the porosity caused by the amount of foam permitted into it. At a lower density, the foamed mortar contains a higher percentage of porosity which causes the formation of large voids due to the proximity of the air voids, which lead to the coalescing of air voids to form large irregular air voids. Table 2 shows the contribution of the additives in the splitting tensile strength of the foamed mortar. According to Table 2, the foamed mortar specimens with 0.4% of coir fibre (CF-0.4) and 30% of PFA (PFA-30) produced the highest tensile strength in 180 days which was about a 68% increase compared to the control mix, although the initial strengths of both additives were different. The start-up value of the tensile strength of coir fibre was the highest at day 7, about 43% more than the control mix. At each age of testing, the tensile strength of CF-0.4 was unbeaten because of its strong hold capacity between the particles in the specimens.

Table 2 Effect of various additives on the splitting tensile strength

Sample	Splitting Tensile Force (N/mm^2)			
	7 Days	28 Days	60 Days	180 Days
NFC-2	0.21	0.22	0.25	0.25
POFA-25	0.18	0.28	0.29	0.30
POFA-40	0.13	0.14	0.15	0.16
PF-0.2	0.22	0.29	0.30	0.30
PF-0.4	0.26	0.36	0.36	0.37
SF-0.25	0.21	0.24	0.27	0.28
SF-0.4	0.25	0.28	0.30	0.33
SLF-10	0.25	0.29	0.34	0.35
PFA-15	0.19	0.29	0.32	0.36
PFA-30	0.18	0.27	0.39	0.42
W5-P15	0.20	0.27	0.29	0.34
W10-P15	0.17	0.21	0.23	0.31
CF-0.2	0.28	0.32	0.33	0.37
CF-0.4	0.30	0.41	0.41	0.42

The findings in the table above proved that the amount of fibres influence the enhancement level of the tensile strength. The tensile strength experienced a small reduction with 0.2% of coir fibre (CF-0.2) compared to CF-0.4. The tensile strength of CF-0.4 increased in 7 days, 28 days, 60 days, and 180 days to about 7%, 28%, 24%, and 14%, respectively compared to CF-0.2. Figure 9 below shows the development of the crack formation of CF-0.4 and PFA-30 when being loaded. Both additives showed different types of crack formations because of their shear forces. The foamed mortar with a high fibre inclusion gained higher shear force which prevented the propagation of micro-cracks caused by the imposed load.

A high percentage of fibre can create a strong bonding between the particles of the foamed mortar, thus it is able to absorb energy to resist crack formation. The superior performance of the coir fibre is due to its large diameter, high lignin and low cellulose content, promotes coir as a strong reinforcing agent. Therefore, the splitting tensile force increases gradually with the increase of the fibre content. Besides that, PFA-30 yields better enhancement of the tensile strength due to its pozzolanic reaction during the curing process. Since PFA-30 has no reinforcements, the widening of cracks leads to the failure of the specimen and eventually breaks apart when it tested.

(a) Cracks formed on sample CF-0.4

(b) Cracks formed on sample PFA-30

Figure 9 Development of cracks formed on the foamed mortar sample during tensile strength test (a) for CF-0.4 (b) PFA-30

Due to longest hydration process, the earliest strength that PFA-30 yielded was lower than the control mix at day 7. The hydration of PFA will not be initiated until calcium hydroxide ($Ca(OH)_2$) is liberated from the cement content during hydration. The duration of the setting time will increase with the addition PFA. After 28 days, PFA-30 initiates vigorous strength development until the 180th day and the strength is expected to be enhanced further if the ages are extended [16]. At the same time, PFA-15 achieved a higher early strength than PFA-30 due to the shorter duration of the hydration process to achieve optimum strength. PFA has been found to reduce the interconnection between the capillary pores. The compound (C-S-H) produced from the hydration process makes the foamed mortar denser with fine pores and voids, thus the shear stress is improved to increase the tensile strength [17].

Furthermore, silica fume was also observed to give higher strength than the foamed mortar control mix. Silica fume is no longer an industrial waste by-product but a well-established pozzolanic material which can contribute to the strength of foamed mortar. When compared to PFA-30, silica fume only has a 10% cement replacement, the lowest input of pozzolanic material. Therefore, the rapid reaction of silica fume during the hydration process was recorded and it produced higher early strength and continued to increase until the 180th day but it remained lower than PFA-15 and PFA-30 due to the amount of cement replaced. If the replacement of cement with silica fumes increases, there is a significant increase in the tensile strength of the foamed mortar because of the production of the additional C-S-H compound by the silica during the hydration process. Uniform pore sizes and formation will be induced during the hydration process, thus the maximum stress increases, so that it resists more imposed loads before failure [18].

On the other hand, POFA-25 has provided better tensile strength than POFA-40 until the 180th day but POFA-40 was unable to overcome the value of the control mix even once. Although it undergoes pozzolanic reaction during the hydration process, a high content of POFA failed to give noticeable strength over a longer curing period. From the investigation, it can be concluded that a higher tensile strength of foamed mortar will be obtained if the content of POFA is at a lower level [19].

Though, 10% and 20% replacement of sand with POFA exhibited higher tensile strength than the control mix at the age of 90 days due to the reduction of fine aggregates. Meanwhile Abdullah *et al*. (2010) stated that the replacement level of POFA with cement about 20% provides optimum strength in aerated concrete. The enhancement of the tensile strength of foamed mortar incorporated with POFA as a cement replacement was produced by the formation of calcium silicate hydrates. Therefore, it required a high imposed load to split the cylindrical specimens [20]. Generally, splitting tensile strength of foamed mortar with POFA as a cement replacement shares the same trend as in compressive strength [21].

Wood ash blended with PFA in the foamed mortar mix showed a similar development trend as in compressive and flexural strength. Due to the weak pozzolanic activity [22], from the results obtained the splitting tensile strength was observed to decline when there is an increase of wood ash in the foamed mortar as cement replacement. When minimum amounts of wood ash (5%) was added with PFA-15, the tensile strength remained high and is expected to increase over the testing ages. The tensile strength with 10% wood ash also showed an increasing pattern over the testing ages when compared to the control mix and produced a very minor reduction in the strength development compared to 5% wood ash. If the percentage of wood ash added is higher, the strength will be reduced significantly, but there was no vigorous drop recorded in the strength over the testing ages due to the addition of high pozzolanic materials (PFA-15). The reduction in the tensile strength might be due to the weak bonding between the cement paste and the wood ash.

Both percentages of steel fibres 0.25% (SF-0.25) and 0.4% (SF-0.4) produced high tensile strengths than the foamed mortar normal mix. In 180 days, the value of the tensile strength of SF-0.4 increased about 32% more than the foamed mortar normal mix; meanwhile, SF-0.25 only gained about 12%. From this result, it is proven that steel fibre contributed towards better mechanical properties of foamed mortar, especially in tensile strength. This strength development may be an indication of the strong bonding between the fibres and the matrix. Usually, increment in the load imposed initiates the development of critical cracks and eventually lead to concrete failure. Thus, the steel fibres play the role of a means of stress transfer whereby the stress passes through the fibres which can delay the propagation of cracks and enhance the shear strength of the foamed mortar [23].

Polypropylene fibre has produced good strength compared to the control mix specimens due to the strong connectivity between each particle with the fibre. The strength of PF-0.4 continuously rose up from the 7th day until the 180th day. From the results shown, it can be concluded that a high dosage of fibre is needed in order to enhance the mechanical properties of the foamed mortar. Polypropylene fibre was used as a reinforcing agent in cementations matrix and was able to enhance the strength and absorb energy to gain more tensile strength. The stress and deformation capability of the specimen increased considerably with the inclusion of polypropylene fibres to the mixtures. Randomly oriented fibres arrest micro cracks and limit the widening of cracks during testing, thus improving ductility and strength [23]

5.0 CONCLUSION

The findings show that the amount of fibres influences the enhancement level of the tensile strength. A high percentage of fibre can create a strong bonding between the particles of the foamed mortar, thus it is able to absorb energy to resist crack formation. The superior performance of the coir fibre is due to its large diameter, high lignin and low cellulose content, promotes coir as a strong reinforcing agent. Therefore, the splitting tensile force increases gradually with the increase of the fibre content. Besides that, PFA-30 yields better enhancement of the tensile strength due to its pozzolanic reaction during the curing process. Since PFA-30 has no reinforcements, the widening of cracks leads to the failure of the specimen and eventually breaks apart when it tested.

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