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# Influence of Oil Palm Empty Fruit Bunch (EFB) Fibre on Drying Shrinkage in Restrained Lightweight Foamed Mortar

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***Abstract:** Currently, the attention on natural fibre reinforced concrete based materials could be seen increasingly rising around the world in the quest for economic and environmental importance in the construction sector and built environment. Hence this research will focus on inclusion of oil palm empty fruit bunch (EFB) fibre on drying shrinkage of lightweight foamed mortar (LFM). There were three densities of LFM was considered which were 800kg/$m^3$, 1100kg/$m^3$ and 1400kg/$m^3$.The size for the empty fruit bunch (EFB) fibre was between 15-19mm with diverse volume fractions of 0.15%, 0.30%, 0.45% and 0.60% by LFM mix volume. The drying shrinkage test was performed according to American Standard ASTM C157. The test specimen dimension is a 75mm x 75mm x 275 mm prism shaped utilising a standard stainless mould which conforms to ASTM C490. The experimental results revealed that the inclusion of 0.3% EFB fibre in 800 kg/$m^3$ density, 0.45% EFB fibre in 800 kg/$m^3$ and 1400 kg/$m^3$ densities possess the lowest percentage value of drying shrinkage at the final age of testing compared to control specimen and other EFB fibre volume fraction. In addition, EFB fibre exhibits a micrometer level diameter and hydrophilicity attributes which make it highly dispersible. It also has a capability to be distributed homogeneously along with the synchronicity of a great fibres quantity in unit volume of LFM.*

***Keywords:** foamed mortar, shrinkage, crack, concrete, fibre, oil palm*

## I.INTRODUCTION

Currently, the attention on natural fibre reinforced concrete based materials could be seen increasingly rising in Malaysia in the quest for economic and environmental importance in the construction sector and built environment. There are numerous types natural fibres utilised broadly in industries for making Lightweight Foamed Mortar (LFM). The main reason for adding the natural fibres in LFM is to augment the physical and mechanical performances [1].

The natural fibres can play an important role in improving the bonding between the cement matrixes which will improve the drying shrinkage of LFM [2]. Contraction when drying shrinkage is described by the loss of liquid from concrete when left in dry air [3]. LFM shows a greater contraction when measured against standard concrete. Moist-cured LFM specimens with a base mix composed of neat cement showed drying shrinkage values greater than standard cement by a factor of 10 [4]. The absence of aggregates and the elevated grout/fine aggregate constituents resulted in the greater higher drying shrinkage values in LFM. The greater shrinkage values showed by LFM can also be sourced to it having more cement and water [5]. Normal shrinkage values for LFM are between 0.06 to 0.6% [6]. A 30% substitution by fine fly ash in place of cement in a LFM mixture with a density of 1400kg/$m^3$ resulted in lower shrinkage strain measurements, compared to 0% fine fly ash that resulted in readings 2.6 times higher [7]. The cause is the restraint provided by the unreacted fly ash particles in the blend. The same research additionally demonstrated that substituting fine sand in a LFM mixture with coarse fly ash at proportions of 50% and 100% resulted in greater drying shrinkage strains compared to the 100% sand LFM mixture. The researchers postulated the rise in shrinkage strains are caused by the higher level of actual water content in the coarse fly ash blend and as a result of the higher amount of paste than its counterpart sand samples. Nambiar and Ramamurthy [8] investigated the effects of density, moisture content, proportion of filler to cement, substituting sand with fly ash using different substitution amounts, and foam volume on the shrinkage of preformed foam concrete. The findings demonstrated a decline in shrinkage values when using a higher proportion of filler to cement. The researchers suggested that lower cement composition and the restraining effects of a higher percentage of fine aggregate contents were responsible. The findings agreed with the conclusions of Jones and McCarthy [9] whereby substituting fly ash for sand leads to greater drying shrinkage measurement. They also demonstrated that a LFM mixture made up of 30% foam and a 40% substitution of sand by fly ash would show a 20% higher drying shrinkage compared to corresponding cement-sand mixtures [10]. The finding also demonstrated a rise in foam volume results in a lower drying shrinkage in LFM.

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The researchers suggested this decline to the fact that the micro-pores influencing the contraction is in proportion to the paste volume in a LFM mixture. Therefore, a decreased drying shrinkage values is a consequence of a lower paste volume in the LFM mix. The researchers also came to the realisation that lower density LFM mixes are more stable than heavier mixes in terms of their shrinkage measurements. They argued that artificial air pores could have been a factor in affecting volume stability by allowing some shrinkage and this effect rises with a rise in foam volume. This is in opposition to the finding of Brady *et al.*, 2001[11] which argued that lighter LFM mixtures (with higher foam volumes) show greater drying shrinkage measurements when compared to heavier LFM mixtures with inferior foam volumes [12]. The drying shrinkage of LFM is not usually considered to be important when it is used as filler and for roof deck insulation applications. However, drying shrinkage of LFM should be taken into account in structural applications [13].

## II.EXPERIMENTAL PROGRAM

### 2.1 Materials

In this study, Type I Portland cement was utilized. This Type 1 Portland cement fulfils the requirement stated in BS-EN12. The fine aggregate used has the fineness modulus of 3.15, specific gravity of 2.67 and a maximum aggregate size of 4.8mm and the coarse aggregate was crushed gravel passed through 10mm sieve. The water-cement proportion was kept steady all through this study, which is 0.38. Noraite PA-1 protein based surfactant was utilized. The ratio of foaming agent to water is 1:30 by volume. The foam density was controlled to be between 65-75 kg/m³. The size for the empty fruit bunch (EFB) fibre was between 15-19mm with diverse volume fractions of 0.15%, 0.30%, 0.45% and 0.60% by LFM mix volume. Figure 1 shows the EFB fibre used for this study.

**Fig.1 1EFB fibre utilized for this research**

### 2.2 Mix Design

Table 1 portrays in detail the mix design used in this research. A mix design of LFM will be tested in designated densities of 800kg/m³, 1100kg/m³ and 1400kg/m³.There were a total of 15 mixes we prepared in turn to observe the shrinkage behavior of LFM with different percentages of EFB fibre addition by mix volume.

**Table. 1 Mix design proportion for all three densities**

| Sample Code | Density (kg/m$^3$) | Cement (kg) | Fine Aggregates (kg) | EFB Content (kg) | Water content (kg) |
|---|---|---|---|---|---|
| CNTRL-8 | 800 | 15.12 | 22.68 | - | 6.81 |
| 0.15EFB-D8 | | | | 6.69 | |
| 0.30EFB-D8 | | | | 13.38 | |
| 0.45EFB-D8 | | | | 20.00 | |
| 0.60EFB-D8 | | | | 26.76 | |
| CNTRL-11 | 1100 | 20.54 | 30.81 | - | 9.24 |
| 0.15EFB-D11 | | | | 9.08 | |
| 0.30EFB-D11 | | | | 18.17 | |
| 0.45EFB-D11 | | | | 27.26 | |
| 0.60EFB-D11 | | | | 36.35 | |
| CNTRL-14 | 1400 | 25.96 | 38.93 | - | 11.68 |
| 0.15EFB-D14 | | | | 11.48 | |
| 0.30EFB-D14 | | | | 22.97 | |
| 0.45EFB-D14 | | | | 34.45 | |
| 0.60EFB-D14 | | | | 45.94 | |

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### 2.3 Testing setup

The volume of concrete shifts directly subsequently after setting. This may occur in the form of swelling or shrinkage. In any case, the former increasingly occur because of the loss of water amid the hydration of evaporation and cement. On the off chance that the dampness is removed, and the solid isn't limited from development, at that point shrinkage is normal when the particles will in general draw nearer to one another.

In this research, the drying shrinkage test was performed utilising the technique that was endorsed in American ASTM C157 [14]. The test specimen dimension is a 75mm x 75mm x 275 mm prism shaped utilising a standard stainless mould which conforms to ASTM C490 [15]. The mortar bars were manufactured with a cast-in steel entryway stud on which the length change estimation was taken after 24hours the mortar bars were de-moulded. That is to say, the bars were removed from the steel mould one day after casting.

Drying shrinkage estimation was performed with the position of reference bar in the instrument and the perusing demonstrated by the digital meter and was recorded. At that point, the specimen bar was put in the instrument and turned as shown in Figure 2. The test examples were set at a similar position each time when a comparison reading is taken. Any extraordinary length change at any age was determined using Equation (1)

$$L = \frac{Lx - Li}{G} x\ 100 \qquad (1)$$

Where $L$ is the change in length as age x (%), $L_x$ is the difference between the comparator reading of the reference bars and specimens at age x. $L_i$ is the distinction between the comparator reading of the reference bars and specimens when the initial reading was taken. G is the gauge length (standard specimen is 250mm).

**Fig. 2 Drying shrinkage testing**

## III.RESULTS AND DISCUSSION

Drying shrinkage of LFM has become the most common source of shrinkage cracking. It transpires in hardened LFM as a result of water movement. During the hardening process of LFM, the formation of C-S-H gel resulting different size of voids. As drying happens, disjoining pressures eliminates absorbed water and hydrostatic forces which also known as capillary stresses create a meniscus that apply pressures on the C-S-H skeleton instigating the cement matrix to shrink.

Drying shrinkage of LFM can be a serious problem where the absence of course aggregate in LFM makes the particles tend to get nearer with the evaporation of water hence upsurges the drying shrinkage of LFM. It is generally accepted that the existence of short fibres inside the cementitious matrix of LFM improves its drying shrinkage. In the low densities of LFM cementitious specimens (500 kg/m$^3$ to 1000 kg/m$^3$), the drying shrinkage effects are more prominent in comparison with high densities LFM (1100 kg/m$^3$ to 1900 kg/m$^3$). Hence, the addition of EFB fibre could enhance the bending strength in this material. Table 2, Table 3 and Table 4 show the drying shrinkage recorded for 800 kg/m$^3$, 1100 kg/m$^3$ and 1400 kg/m$^3$ densities respectively and Figure 3, Figure 4 and Figure 5 demonstrate the plotted graph of 800 kg/m$^3$, 1100 kg/m$^3$ and 1400 kg/m$^3$ LFM densities drying shrinkage of different EFB fibre volume fraction correspondingly. From Figures 3 to 5, it can be clearly seen that the control LFM with an increasing density would reduce the shrinkage. Addition of EFB fibres had improved the drying shrinkage intensely. For instance, the percentage of drying shrinkage improvement compared to control specimen at day-28 was about 50% for 800 kg/m$^3$ density with 0.30% EFB fibre, around 92% for 1100 kg/m$^3$ density with 0.45% EFB fibre and 71% for 1400 kg/m$^3$ density with 0.45% EFB fibre. EFB fibre plays an important role as the support system in a macro uniform random distribution of LFM matrix where it could defer and inhibit the rate and the progress of initial plastic shrinkage during the process of LFM hardening. Simultaneously, a contraction forms a crack within the LFM are prohibited by the EFB fibre during the process of cracks progress, which can devour some shrinkage stress whereby the EFB fibre could also diminish the tip stress concentration to stop propagation of the extension and growth of the crack.

Besides, for control LFM specimens, the drying shrinkage keeps on growing severely from day-28 to day-60. Anyhow, inclusion of EFB fibre abridged the long term drying shrinkage (refer to Day-60) for all EFB volume fraction considered in this research. According to Saje*et al.*[16], addition of natural and synthetic fibres in cement base material have the capability to eradicate water, therefore delaying the water evaporation rate and lessening the drying of LFM shrinkage. During the mixing preparation process, EFB fibre was uniformly dispersed throughout the mortar slurry mixture in which it provides spatial strengthening throughout the LFM volume. Hence delivers the composition optimization that inhibits the possibility of the creation and development of severe cracks in LFM. A distributed EFB fibre in the cement matrix play an important role as a nucleation site, which leads to the progress of fibrillary structure on the LFM pore structure, which sequentially safeguards its stability and regularity. Besides, it also ensures a formation of systematic structure orientated super molecular sheath on the EFB fibre. This certainly decreases the LFM shrinkage. It is supported by Roohollah *et al.*[17] in which he stated that the increase in fibre percentage addition in cement based material will reduce the drying shrinkage. Fibre addition has been proven effective in reducing the shrinkage percentage. As far as LFM is concerned, no presence of aggregates could make it to shrink even more as compared to a normal strength concrete [18]. However with the presence of EFB fibre, it acts as the aggregate with the ability of void filling thus lessening the drying shrinkage percentage of LFM [19]. The EFB fibre is more effective in reducing shrinkage and also able to reduce the cracking percentage in the cement matrix. Furthermore, EFB fibre exhibits the capability to mend a crack after the initial crack happens, providing an early signal to prevent it from expanding further [20, 21].

Figures 3 to 5 demonstrate that 0.3% EFB fibre in 800 kg/m$^3$ density, 0.45% EFB fibre in 800 kg/m$^3$ and 1400 kg/m$^3$ densities has the lowest percentage value of drying shrinkage at the final age of testing compared to control specimen and other EFB fibre volume fraction. These patterns of result are in line with the finding of Saje *et al.* [16] in which the water eliminating ability of EFB fibre determines the drying shrinkage value of LFM specimens. EFB fibre possess an excellent dispersibility due to its hydrophilicity and micrometer level diameter in enabling a uniform distribution along with a great amount of fibres in unit volume of LFM, which significantly restrain the LFM drying shrinkage due to EFB fibre barrier [22]. During the development process of drying shrinkage, the EFB fibre in LFM consume more energy by holding back the drying shrinkage which prevent the drying shrinkage to be further developed [24].

**Table. 3 Drying shrinkage recorded for 800 kg/m$^3$ density LFM**

| Mix | Day-1 | Day-3 | Day-7 | Day-14 | Day-21 | Day-28 | Day-60 |
|---|---|---|---|---|---|---|---|
| Control | 0.28mm | 0.38mm | 0.43mm | 0.46mm | 0.52mm | 0.57mm | 0.71mm |
| 0.15EFB | 0.22mm | 0.31mm | 0.36mm | 0.41mm | 0.47mm | 0.49mm | 0.54mm |
| 0.30EFB | 0.12mm | 0.20mm | 0.23mm | 0.29mm | 0.35mm | 0.38mm | 0.41mm |
| 0.45EFB | 0.15mm | 0.25mm | 0.31mm | 0.38mm | 0.45mm | 0.48mm | 0.49mm |
| 0.60EFB | 0.19mm | 0.29mm | 0.32mm | 0.39mm | 0.48mm | 0.52mm | 0.58mm |

**Table. 4 Drying shrinkage recorded for 1100 kg/m$^3$ density LFM**

| Mix | Day-1 | Day-3 | Day-7 | Day-14 | Day-21 | Day-28 | Day-60 |
|---|---|---|---|---|---|---|---|
| Control | 0.23mm | 0.27mm | 0.36mm | 0.40mm | 0.43mm | 0.48mm | 0.61mm |
| 0.15EFB | 0.09mm | 0.18mm | 0.23mm | 0.28mm | 0.32mm | 0.37mm | 0.44mm |
| 0.30EFB | 0.07mm | 0.15mm | 0.27mm | 0.30mm | 0.32mm | 0.35mm | 0.41mm |
| 0.45EFB | 0.04mm | 0.12mm | 0.12mm | 0.19mm | 0.23mm | 0.25mm | 0.28mm |
| 0.60EFB | 0.12mm | 0.17mm | 0.25mm | 0.27mm | 0.29mm | 0.39mm | 0.47mm |

**Table 5 Drying shrinkage recorded for 1400 kg/m$^3$ density** LFM

| Mix | Day-1 | Day-3 | Day-7 | Day-14 | Day-21 | Day-28 | Day-60 |
|---|---|---|---|---|---|---|---|
| Control | 0.15mm | 0.21mm | 0.28mm | 0.35mm | 0.38mm | 0.41mm | 0.48mm |
| 0.15EFB | 0.10mm | 0.17mm | 0.23mm | 0.31mm | 0.32mm | 0.35mm | 0.39mm |
| 0.30EFB | 0.06mm | 0.11mm | 0.15mm | 0.23mm | 0.29mm | 0.33mm | 0.36mm |
| 0.45EFB | 0.04mm | 0.09mm | 0.12mm | 0.17mm | 0.21mm | 0.24mm | 0.26mm |
| 0.60EFB | 0.08mm | 0.14mm | 0.19mm | 0.29mm | 0.35mm | 0.37mm | 0.42mm |

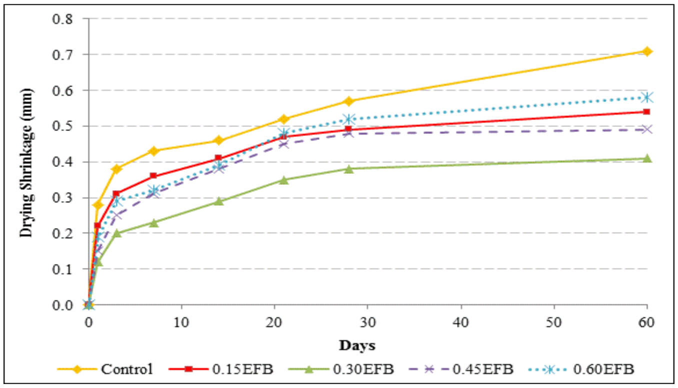

**Fig. 3 Drying shrinkage of 800 kg/m$^3$ density LFM of different EFB fibre volume fraction**

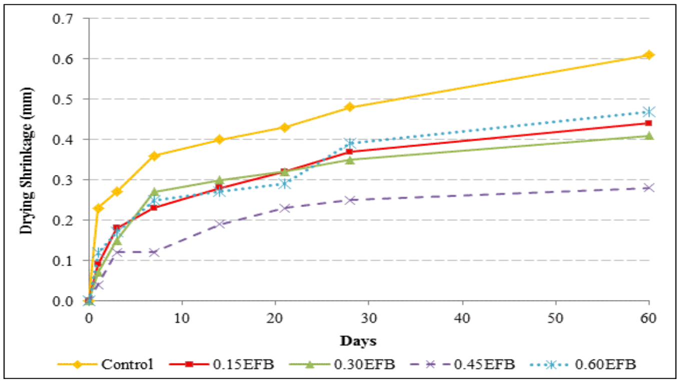

**Fig. 4 Drying shrinkage of 1100 kg/m$^3$ density LFM of different EFB fibre volume fraction**

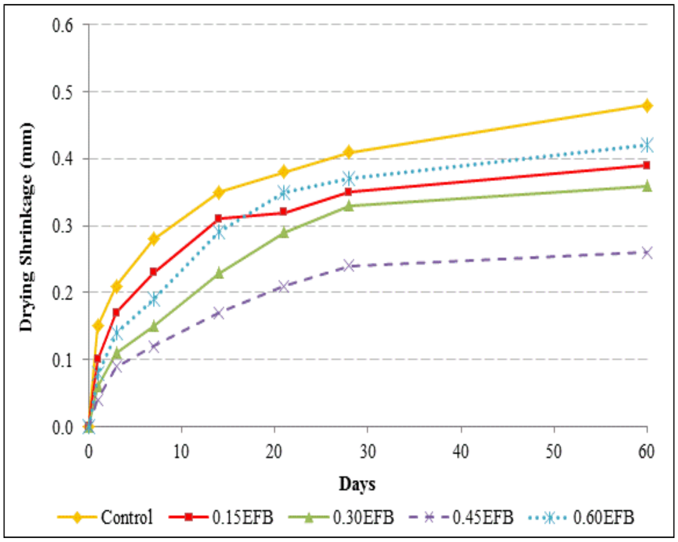

**Fig. 5 Drying shrinkage of 1400 kg/m$^3$ density LFM of different EFB fibre volume fraction**

## IV.CONCLUSIONS

The effects of drying shrinkage were more prominent in low densities mix of LFM rather than in the mix with higher densities. Hence, the EFB fibre was included for the purpose of overcoming the weaknesses of this material and thus improving the shrinkage behaviour. Based on the results presented in this paper, it can be concluded that the inclusion of 0.3% EFB fibre in 800 kg/m$^3$ density, 0.45% EFB fibre in 800 kg/m$^3$ and 1400 kg/m$^3$ densities possess the lowest percentage value of drying shrinkage at the final age of testing compared to control specimen and other EFB fibre volume fraction. In addition, EFB fibre exhibits a micrometer level diameter and hydrophilicity attributes which make it highly dispersible. It also has a capability to be distributed uniformly along with the coexistence of a great fibres quantity in unit volume of LFM.

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