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# ENVIRONMENTALLY FRIENDLY VEGE-ROOFING TILE: AN INVESTIGATION STUDY

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**Abstract**

This paper presents a research study conducted on the usage of vegetable oil as a binder for roofing tile. Conventionally the roofing tiles used by construction industry are either concrete or clay roofing tiles in which cement and heat curing is used as a binder. Both of these material types utilize a large amount of energy for their manufacture, making it environmentally unfriendly because of high content of $CO_2$ emission during its production. To cater this problem, a novel methodology of producing roofing tiles with vegetable oil (palm oil) is used in this study, as it does not require the use of any form of cementitious or pozzolanic materials or water. These manufactured tiles would be considered more environmentally friendly than cementitious and kiln manufactured tiles, both of which are high energy consumers. Limited trails were conducted and it was found that when a pre-determined amount of vegetable-oil was blended with graded mineral aggregates (river & mining sand) with fly ash as filler and then compacted into moulds, subsequently heat cured in oven for durations ranging from 6 to 10 days have shown flexible strength up to 23MPa. The achievement of strength is dependent on mix proportions and tile dimensions. It was observed that curing resulted in complex autocatalytic oxy-polymerization set of reactions which converted the vegetable oil into a rigid solid binder. All prototype samples were tested for water absorption, permeability and flexural strength according to ASTM Standards. The results obtained from prototype sample (15mm x 100mm) prepared with 50% and 35% filler achieved the flexural strength up to 23MPa and 21MPa respectively when cured at 190$^{o}$C.

**Keywords:**

Vege Roofing Tile; Vegetable Oil; Embodied Energy; $CO_2$ Emission

## 1 INTRODUCTION

Global warming the major issue of concern of today has attracted all government and non-governmental organization to put a cap on the carbon dioxide emission, Alarming increase in human and industrial activities with wide exploitation of resources are now becoming threat for environment. These threats lead researchers to think for sustainable development [Bozell & Patel 2006]. Thus to resolve this issue, use of green chemistry is considered as one of the useful way to overcome the problem of utilizing hazardous substances in manufacturing processes [Anastas & Warner 1998]. The use of this field is considered to be more environmentally friendly because of the use renewable raw materials [Baumann, 1988]. Malaysia being a fast growing economic country also ratified the Kyoto Protocol in 2002 to put a cap on greenhouse gas emission [NC2, 2013]. In Malaysia's Second National Communication submitted to the UN convention on climate change, Malaysia voluntarily aspires to reduce Greenhouse Gases (GHG) emissions intensity of Gross Domestic Product (GDP) by up to 40% of 2005 levels by 2020. This translates into emitting only about 60% of the 2005 GHG emissions in the production of each unit of GDP. In construction industry roofing tile are considered as vital building element. Most of the tiles currently used by construction industry are composed of either concrete or fired clay. Both of these material types utilizes large amount of energy for their manufacture, making it highly environmental unfriendly because of high content of $CO_2$ emission during its production. This suggests that converting these highly energy consumable processes into less energy consumable processes will definitely reduce the $CO_2$ emission and would be helpful in achieving the target.

*Tab.1: Embodied energy and $CO_2$ associated with production of masonry units and tiles.*

| Materials | Embodied Energy EE (MJ/kg) | Embodied Carbon EC ($kgCO_2/kg$) |
|---|---|---|
| Clay brick | 3.0 | 0.23 |
| Aggregate | 0.083 | 0.0048 |
| Cement | 5.50 | 0.93 |
| Concrete (8/10MPa) | 0.70 | 0.65 |
| Clay tile | 6.5 | 0.45 |
| Ceramic tile | 12.0 | 0.74 |

It was observed that till now majority of studies were conducted in replacing the aggregate component used for the manufacturing of roofing tile with recycled materials such as fly ash, incinerated sewage sludge ash, municipal solid waste, incineration fly ash and etc., but rather limited work has been conducted on reducing the energy consumed in manufacturing of the binder component used in binding the tiles, such as cement binder in concrete tiles and kiln firing in clay tiles.

According to Hammond and Jones (2011), the estimated embodied energy and $CO_2$ associated with the production of masonry units and tiles are as shown in Table 1. Most of the embodied energy and $CO_2$ are related to the binding effect, such as firing in clay bricks and cement production in concrete blocks. In comparison, aggregate has much less impact on the environment and energy consumption.

The use of vegetable oil in construction industry already is the area of interest for the researchers. However, little work has been done in this area and therefore it needs much focus and research. Limited trials conducted by the researchers Zoorob and Froth on manufacturing of building blocks (Vegeblocks) using vegetable oil, have shown that by appropriate selection of ingredient materials, adequate compaction and heat curing, compressive strengths of more than 25MPa are achievable [Zoorob, Froth & Bailey 2006]. Froth and Zoorob reported that waste vegetable oil when mixed with recycle materials could be converted into a product called Vegeblock at ambient temperature. The use of vegetable oil in construction industry will reduce the environmental impacts caused by carbon dioxide emission [Forth & Zoorob 2006].

This study is conducted in line with Malaysian's National plan to reduce $CO_2$ emission. It investigates the utilization of vegetable oil (edible oil of any type) as a binder in building roofing tiles, thereby replacing any form of cementitious or pozzolanic materials or water. The study will focus on preparation of sample vege roofing tile in cooperating different percentage of oil content and then followed by testing of fabricated sample tile for water absorption, permeability and flexural strength.

## 2 MATERIALS AND METHOD

### 2.1 Vegetable Oil

Palm oil used was obtained from local market, which is double fractionated super grade 100% pure palm olein. It consists of 49.3% saturated fatty acid, 12.1% polyunsaturated and 43.6% mono saturates.

### 2.2 Sand Aggregate

The sand used was of two types, namely river sand and mining sand. The size distribution was obtained from sieving in accordance with ASTM C67-13 [ASTM, C 163].

### 2.3 Filler

Fly ash of size less than 75µm was used as filler for the preparation of all samples.

### 2.4 Specimen Preparation

Specimen were prepared using 50% of each sand type (river & mining) mixed with fly ash filler with the content varying from 20% to 50%. The net amount of aggregate and filler for the preparation of sample specimen was 250g. The percentage of oil used varies between 5% - 7%. After thorough mixing of vegetable oil with aggregate and filler, the mix was transferred to standard Marshall Molds (50 mm × 100 mm) and compacted with 10 blows using Marshall compacting machine to attain a 15 mm thick tile sample specimen. The samples were then transferred to oven for heat curing maintained at a temperature at 200±2°C from 3 days to 10 days. The mixing ratio (sand, filler & oil) and heat curing duration is shown in Table 2.

## 3 TESTING PROCEDURE

Triplicate samples prepared with varying content of oil and fly ashes and were tested for water absorption [ASTM, C 67-13], permeability [ASTM C1167-03] and flexural strength [ASTM, C 67 -13].

*Tab. 2: Properties of roofing tile specimens.*

| Sample No. | Filler (Fly ash) % | Sand 1 River Sand % | Sand 2 Mining Sand % | Oil (Palm oil) % | Compaction Blows | Temperature °C | Curing Days |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 40 | 40 | 5.22 | 10 | 200 | 3 |
| 2 | 25 | 37.5 | 37.5 | 5.43 | 10 | 200 | 3 |
| 3 | 30 | 35 | 35 | 5.65 | 10 | 200 | 4 |
| 4 | 35 | 32.5 | 32.5 | 5.87 | 10 | 200 | 5 |
| 5 | 40 | 30 | 30 | 6.09 | 10 | 200 | 5 |
| 6 | 45 | 27.5 | 27.5 | 6.52 | 10 | 200 | 5 |
| 7 | 50 | 25 | 25 | 6.96 | 10 | 200 | 5 |

Specific gravity and porosity were calculated for all samples to ensure uniformity in test results using equations (1) and (2).

$$S.G\,mix = \frac{100}{\frac{\%\,filler}{S.G\,filler} + \frac{\%\,sand\,1}{S.G\,sand\,1} + \frac{\%\,sand\,2}{S.G\,sand\,2} + \frac{\%\,oil}{S.G\,oil}} \qquad (1)$$

$$P = 100\left(1 - \frac{D}{S.G}\right) \qquad (2)$$

where, *S.G* = specific gravity, *D* = density and *P* = Porosity.

# 4 RESULTS AND DISCUSSION

## 4.1 Water Absorption

Water Absorption or sorptivity is a measure of moisture transport and considered as an important factor in determining the concrete durability [Dias 2000]. Table 3 shows the percentage of water absorbed and permeability test of concrete. The water absorption was calculated as:

$$Absorption\,\% = W_w T_{24} - \frac{W_w T_0}{W_A - W_w T_0} \qquad (3)$$

where, $W_A$ = Mass in air, $W_W T_0$ = Mass in water at zero time and $W_W T_{24}$ = Mass in water after 24 hrs

Results showed that water absorption was found to be high for sample having 20% filler and least for 50% fly ash filler in the specimen. Sample prepared with 25% filler content showed lower absorption value in comparison to other higher filler content samples.

## 4.2 Permeability

The greater the permeability of concrete the lower will be the durability performance of concrete [Khan & Lynsdale 2002]. Moreover, large permeability allow the entrance of such molecules that are responsible for the degradation of chemical stability of concrete [Mehta & Monteiro 2006]. The advantage of less permeability is that it acts as a resistance to the penetration of water [Alhozaimy, Soroushian & Mirza 1996]. The permeability test for vege tile specimens was performed according to standard [ASTM-C1167]. Table 3 shows that samples having filler percentage of 30, 35, 45 and 50 passed the test. The rest of samples were quite permeable. This is due to the reason that more filler was used in these samples. But adding an increase amount do not guarantee an impermeability since some optimum value for filler percentage needs to be evaluated. It is noteworthy that in most cases tensile strength and fracture properties becomes worse if the large amount of filler is added [Naik, Kraus, Chun & Botha 2006].Thus the optimum level of filler percentage to be used for vege roofing tile considered to be 35% to 50% filler respectively.

## 4.3 Flexural Stress

Flexural stress (σ) is expressed in MPa.

$$Flexural\ Stress = \frac{MC}{I} \qquad (4)$$

where, M = unit load, C = distance from the neutral axis and I = moment of inertia of cross section

Table 3 shows that apart from the fact that 5 samples passed the permeability test, the flexural stress for samples having 35 and 50% filler respectively were the highest. Thus the samples having 35% and 50% filler were consider to be optimum since they were less permeable and showed good flexural stress. These two samples were subjected to further investigation with increased curing time and by keeping all other compositions same as used before as shown in Table 4 and Table 5 respectively. However, it was noticed that if samples were cured for more than 5 days at 200˚C cracks do appear. It was thus decided to reduce the temperature to 190˚C for more than 5 days curing. Figure 1 shows flexural strength of Vege roofing tile with 35% fly ash filler. From the figure it is observed that maximum strength was achieved for 7 days of curing and then decreases. Further work needs to be done to understand the oxy polymerization reaction of oil with respect to time of curing which is mainly responsible for strength of vege tile. Similarly, 50% filler samples when cured at 190˚C, showed maximum flexural stress of 23 MPa for 10 days of curing period as shown in Figure 2.

*Tab. 3: Percentage of water absorption and permeability of different percentages of filler cured at 200°C.*

| No | Filler, % | Oil, g | Compaction (blows) | Temperature, ºC | Absorption, % | Permeability | Flexural stress, MPa |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 12 | 10 | 200 | 6.94 | Fail | 8.725 |
| 2 | 25 | 12.5 | 10 | 200 | 1.98 | Fail | 12.256 |
| 3 | 30 | 13 | 10 | 200 | 2.97 | Pass | 12.394 |
| 4 | 35 | 13.5 | 10 | 200 | 2.04 | Pass | 12.854 |
| 5 | 40 | 14 | 10 | 200 | 2.41 | Pass | 10.876 |
| 6 | 45 | 15 | 10 | 200 | 3.29 | Pass | 11.717 |
| 7 | 50 | 16 | 10 | 200 | 1.72 | Pass | 13.577 |

*Tab. 4: Flexural strength and permeability test results for 35% filler at different curing time at 190°C.*

| No | Curing time , days | Oil content % | Compaction | Flexural stress, σ | Permeability Test |
|---|---|---|---|---|---|
| 1 | 6 | 5.87 | 10 | 17.7 | Pass |
| 2 | 7 | 5.87 | 10 | 21.5 | Pass |
| 3 | 8 | 5.87 | 10 | 19.5 | Pass |
| 4 | 9 | 5.87 | 10 | 17.2 | Pass |
| 5 | 10 | 5.87 | 10 | 11.1 | Pass |

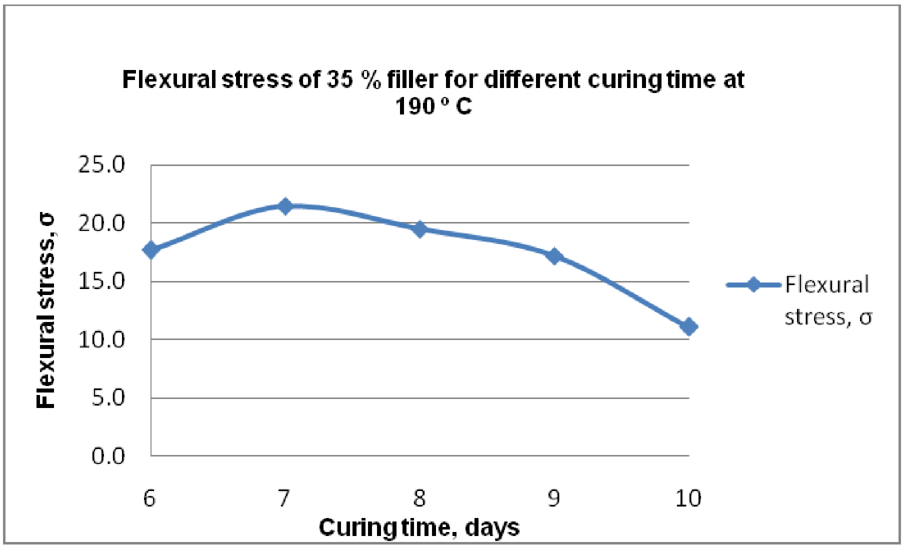


*Fig. 1: Flexural strength of Vege roofing tile with 35% fly ash filler.*

*Tab. 5: Flexural strength and permeability test results for 50% filler at different curing time at 190°C.*

| No | Curing time , days | Oil content % | Compaction | Flexural stress, σ | Permeability Test |
|---|---|---|---|---|---|
| 1 | 6 | 6.96 | 10 | 13.0 | Pass |
| 2 | 7 | 6.96 | 10 | 16.8 | Pass |
| 3 | 8 | 6.96 | 10 | 16.3 | Pass |
| 4 | 9 | 6.96 | 10 | 19.3 | Pass |
| 5 | 10 | 6.96 | 10 | 23.0 | Pass |

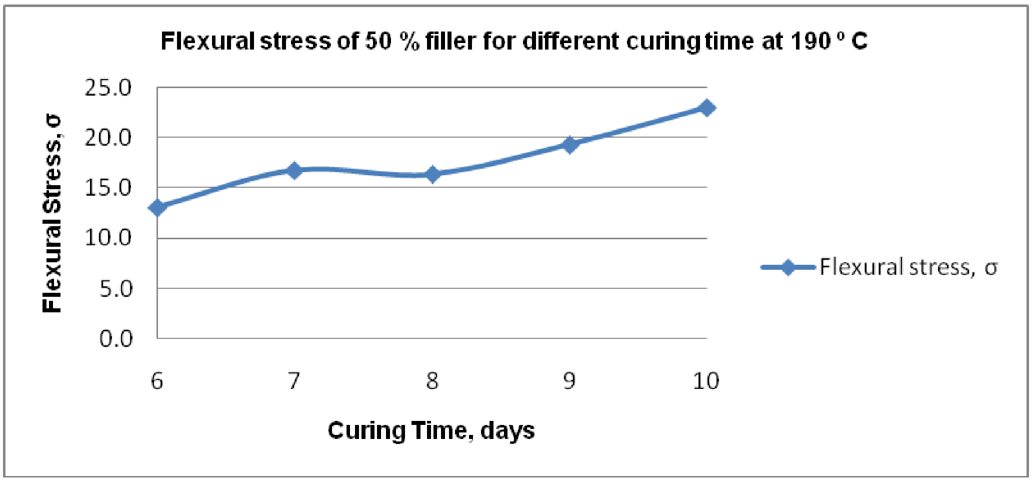


*Fig. 2: Flexural strength of Vege roofing tile with 50% fly ash filler.*

## 5 CONCLUSION

This study reports the investigation of vege roofing tile and concluded that vegetable oil can be used as an alternate binder for manufacturing of roofing tiles. The manufactured vege roofing tiles has meet the criteria for standard concrete or kiln burned clay tile as it showed high flexural strength obtained just at 190˚C oven curing. The sample vege roofing tile also comply with ASTM standard for water absorption and permeability tests. Thus it is considered as a novel technology which has eliminated the use of high energy and helped in production of tiles with lower embodied energy and $CO_2$ emission. From these limited trials it can be safely concluded that the concept of vege roofing tile can be implemented on waste cooking oil also or any oil type (edible or non-edible) as a useful construction material.

## 6 ACKNOWLEDGEMENT

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