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Sustainable and Eco-Friendly Vege Roofing Tiles: An Innovative Bio-Composite

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Abstract. This paper presents a research study conducted on the usage of vegetable oil for the production of eco-friendly Vege roofing tiles. Conventional roofing tiles which constitute of concrete and clay are considered as environmentally unfriendly because of the significant amount of greenhouse gas emission during their production. An entirely novel methodology of utilizing catalyzed vegetable oil is proposed which can totally replace the use of traditional binders like cement and clay. Limited trails conducted on prototypes samples revealed that when catalyzed vegetable oil mixed with aggregates, properly compacted and heat cured at 190ºC for 24 hours, have shown flexural strength up to 9.5 MPa. The superior strength gain of these prototype samples was considered due to the use of the catalyst with vegetable oil, which resulted in the initiation of catalytic oxy-polymerization set of reactions during heat curing, converting vegetable oil to solid, hard polymer which is considered responsible for strength achievement factor for these novel Vege roofing tiles. All prototypes samples were tested for performance indicators like water absorption, permeability, and flexural strength according to ASTM standards. Moreover, the susceptibility of oil leachate from the tiles oil, when tested using electrical conductivity method showed a negligible amount of the electrical conductivity. Moreover, the estimated embodied energy requirements for these tiles were found quite less when compared to conventional tiles.

Introduction

Climate change is one of the foremost issues needs to be addressed at all level of life. One of the major contributors to this change is the burning of fossil fuel, which is considered responsible for the escalation of universe temperature and thus the change of climate. All over the world agencies are working together to cap the emission of carbon dioxide (CO_2) and other greenhouse gases (GHG) into the air. To some extent building sector is also considered as the main source of GHG emission as it accounts 18% of global emissions equivalent to 9 billion tonnes of CO_2 annually [1]. The most alarming fact is that the amount of CO_2 will reach twice the present value if sustainable technologies are not introduced in the construction industry. According to International Energy Agency, around 5% of existing CO_2 emissions is generated only from the cement industry [2]. Moreover, clay tiles which are manufactured by burning of tiles in the kiln at or more than 1000ºC for 2 to 3 days [3], utilizes 1.84–2.8 kJ/kg of energy and discharges 184–244 kg of carbon dioxide (CO_2) per tonne of manufactured product. Thus, the enormous amount of carbon dioxide released during the production of building material also considered responsible for the global warming. This alarming situation needs to be addressed and conservative approaches are needed to be adopted at both manufacturing and extraction of building material which can reduce the amount of energy consumption, thereby reducing GHG emission and also the cost of production.

Vegetable oils are considered as the renewable source since they are extracted from vegetables and herbs [4]. Usage of vegetable oil use as a biofuel has already been investigated by many researchers. However, limited work has been done in the area of utilizing vegetable oil as an effective building material. The most attractive factor of considering vegetable oil as a building material because of it lower embodied energy level during its processing, cropping and plantation which was estimated as 9.7 MJ/kg [5]. Froth and Zoorob have proved that concept of utilization of vegetable oil as a binder for the production of Vege blocks by incorporating waste/recycled aggregates. These blocks showed potential for achieving compressive strengths which were similar to strength concrete blocks [6]. Similarly, the Fly ash, one of the by-products of coal power plants considered as a waste since it is available in enormous quantities and mostly discarded by means of landfill. Research has revealed that the fly ash could be used as filler for the fabrication of ceramic tiles [7]. It was also found that percentage of filler can inversely influence the compressive strength of construction material [8]. Notably, more than 50% fly ash content not only lessens the workability but also attribute to compaction problems [9].

Till today, more stress is laid on investigating the replacement of the aggregates with waste materials but however, a very limited focus was paid in evaluating the energy requirements of binders, such as embodied energy during cement production or kiln firing during clay tile production. Firing clay bricks for strength gain or cement production are considered as the chief contributors in enhancing the embodied energy and CO_2 requirements [10]. Contrary, aggregate has a negligible impact on the environment in contrast to kiln firing and cement production [10]. This research study is conducted to look at the feasibility of eliminating cement and kiln firing for the strength achievement for roofing tile with the use of catalyzed vegetable oil as a binder. Besides this research is conducted on the visionary aim of Malaysia‘s government policy on climate change, where Malaysia voluntarily decided to decrease the GHG emission intensity of GDP by up to 40% from 2005 levels by 2020 [11].

Materials and Method

Materials

Vegetable Oil. Local, double fractionated super grade 100% pure palm olein that constitutes of 49.3% saturated fatty acid, 12.1% polyunsaturated and 43.6% mono saturates was used for this study. The viscosity of virgin palm oil was found as 55.6 cP, while the viscosity of catalyzed oil was found as 59 cP.

Aggregates. Two type of sands namely, river and mining sand was used along with fly ash which was used as filler. The size distribution of sand was obtained by sieve analysis following ASTM, C 136 [12]. Class F fly ash and size less than 75µm was purchased from Kah Hwa Industries SDN. BHD, Malaysia. The proportion of fly ash and sand was taken 50 and 50% respectively. Fig.1 presents the size gradation of sand aggregates.

Catalyst. Qrec, Malaysia brand with 8.33M sulfuric acid (H_2SO_4) having purity of 95-97% was used for this study.

Methodology. Two sets of prototype samples namely, control and catalyzed palm oil were prepared by incorporating natural aggregates, fly ash, virgin palm oil and catalyzed palm oil. All prototype samples were prepared by transferring the mix 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. Virgin palm oil samples were produced by mixing virgin palm oil with aggregates composed of 50% of river sand and mining sand respectively. All compacted samples were cured in an oven at 200ºC for 5 days [13]. Similarly catalyzed oil samples were prepared by utilizing the appropriate amount of catalyst, which was selected between 4 to 6% by molar weight of vegetable oil. Based on physical observation and change in oil physical properties especially its workability, approximately 8% of catalyzed vegetable oil was considered as an optimized value which can be used for mixing with aggregates. The curing temperature for catalyzed oil sample was kept at 190°C. The reduction in curing temperature and curing time in an oven was adopted after observing cracks in all samples when cured at 200°C and above, which was taken for the production of control samples. Both prototypes samples namely, control and catalyzed were investigated for permeability, flexural strength and percentage of water absorption according to ASTM standards [14, 15]. In addition, leachate of oil from prototype samples was tested by using electrical conductivity method after immersing the samples in distilled water at ambient temperature for 4 days. Readings of electrical conductivity were taken for consecutive 4 days. The mixing ratio and heat curing durations for catalyzed oil samples are presented in Table 1.

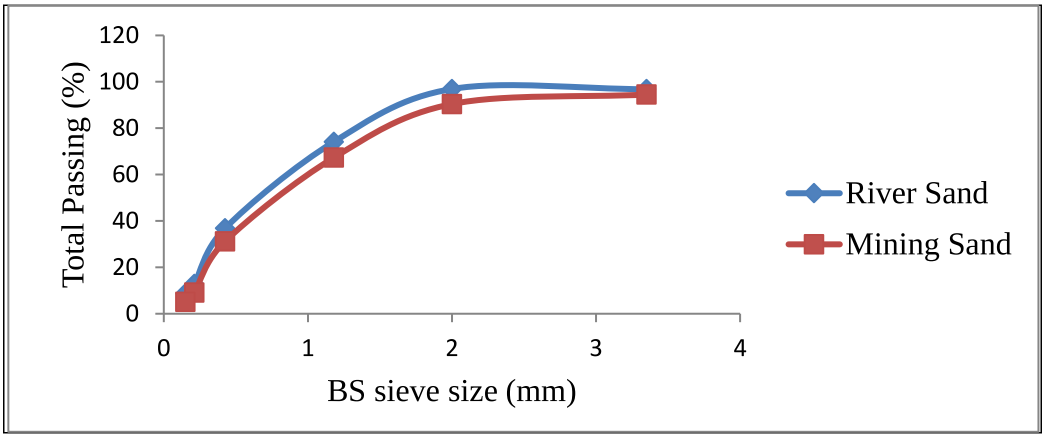

Fig.1: Sieve analysis of sand aggregates

Table 1: Properties of catalyzed tile samples

Filler [%]	River Sand [%]	Mining Sand [%]	Sulfuric Acid [%]	Catalyzed Oil [%]	Compaction Blows	Temperature [°C]	Curing Time [hours]
50	25	25	4-6	8	10	190	8
50	25	25	4-6	8	10	190	16
50	25	25	4-6	8	10	190	24
50	25	25	4-6	8	10	190	32

Table 2: Flexural strength, permeability and water absorption for prototypes samples cured at 190ºC for different curing time

Filler, [%]	Catalyzed Oil [%]	Curing Time [hours]	Temperature, [ºC]	Absorption, [%]	Permeability	Flexural stress, [MPa]
50	8	8	190	2.5	Fail	3.8
50	8	16	190	3.1	Pass	9.6
50	8	24	190	2.8	Pass	9.8
50	8	32	190	2.1	Pass	8.2

Results and Discussions

Permeability. Permeability test was carried out according to the ASTM C 1167-03.The permeability of tiles is not a desired parameter since it influences the durability of the building material like concrete [16]. From the test results as shown in Table 2, it was observed that samples, when cured for 8 hours, failed to pass permeability test. Thus, curing time was increased to 16, 24 and

32 hours. All sample which were prepared at 190°C with curing time greater than 8 hours has passed permeability test. These results clearly indicate that curing time has great influence on completion of oxy-polymerization reaction in which voids were completely replaced by solid polymer coating on the aggregates particles, thereby enhancing the strength and reducing the permeability of the prototype samples. Beside it was noted that catalyzed oil has a significant effect on reducing curing temperature by 10°C, which was previously 200°C for control virgin oil samples. Similarly, the addition of catalyst to vegetable oil has reduced curing time to 24 hours/ 1 day from 5 days.

Water Absorption. Water absorption, a measure of moisture transport considered as an important factor in determining the concrete durability [17]. Percentage of water absorption can be determined as follows:

$$\text{Absorption\%} = (W_wT_{24} - W_wT_0)/(W_A - W_wT_0) \times 100 \qquad (1)$$

where,
W_A = Mass in air , W_WT_0 = Mass in water at zero time , W_WT_{24} = Mass in water after 24 hrs

Results as shown in Table 2 confirms that the percentage of water absorption for all prototypes samples produced by utilizing catalyzed oil at different curing time are within the maximum allowable limit for standard tile which is 6% [18].

Flexural Strength. Flexural strength is the determination of load that a material can withstand without bending. Flexural strength is an important factor for roofing tiles. Flexural strength for all prototype samples were calculated according to the procedure as outlined in ASTM C 67-13 by using the equation

$$\sigma = MC/I \qquad (2)$$

where,

σ = flexural stress, M = unit load, C = distance from the neutral axis, I = moment of inertia of cross section

The results for flexural strength as shown in Table 2 reveals that highest flexural stress was achieved for the samples cured at 190 ºC for 16 and 24 hours. Use of catalyzed oil reduces the curing time by initiating auto – polymerization reaction, responsible for strength gain of all prototype samples. From these intital test results obtained from prototypes samples produced at 24 hours curing time indicates that these tiles have superior performance in terms of flexural strength, low water absorption and impermeablilty.

Based on the above test results, final catalyzed oil prototype test samples were prepared at 8% catalyzed oil content, while keeping constant curing time and tempertaure. All triplicate prototypes were further investigated for flexural stress, permeability and water absorption.

Table 3 presents that all the test results of three prototype samples produced at 190ºC and 24 hours of curing. It was found that all samples were impermeable, the water absorption was within the standard value of 6% [18]. Furthermore, prototypes samples have shown excellent flexural strength in the range of 9 to 10 MPa which is higher in contrast to the minimum flexural strength requirements for burnt clay bricks [19].

Electrical Conductivity. In this study, a unique way of determining the oil leachate from the samples by measuring of electrical conductivity was adopted. Higher the electrical conductivity, higher would be the chances of oil leachate. Higher leaching ability also reflects, higher the permeability and the porosity of the tiles [20]. Fig. 2 shows the results of electrical conductivity of prototypes samples produced at the optimized curing time and after immersing samples in distilled water at ambient temperature for 4 consecutive days. As seen from Fig. 2, a decrease in electrical conductivity values was observed from initial 1st day to final, 4th day.

Thus, it can be safely concluded that addition of catalyst to palm oil initiates oxy-polymerization of oil, which not only increases the viscosity but consequently leads to the hardening of cooking oil [21] resulting in hard, durable vege roofing tile. It further confirms that the chances of oil or acid leachate is almost negligible as catalyzed vegetable oil during heat curing, converted to hard solid polymer.

Table 3: Flexural strength, permeability and water absorption for prototypes samples cured for 24 hrs at 190ºC

Sample No.	Catalyzed Oil [%]	Curing Time [hours]	Temperature, [ºC]	Absorption, WA [%]	Permeability	Flexural stress, FS [MPa]	Variance	S.D
1	8	24	190	1.6	Pass	9.6	FS=0.09 WA=0.3	FS=0.06 WA=0.06
2	8	24	190	2.1	Pass	10.1	FS=0.36 WA=0.2	FS=0.12 WA=0.04
3	8	24	190	2.0	Pass	9.6	FS=0.09 WA=0.1	FS=0.06 WA=0.02

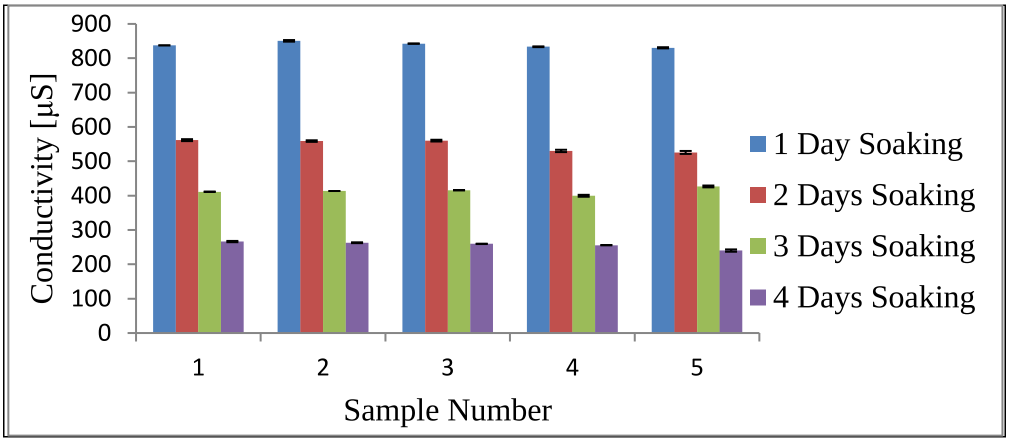

Fig.2: Electrical conductivity for different days of soaking at ambient temperature

Sustainable Characteristics. Sustainability of catalyzed vege-prototype samples was evaluated by means of estimating the embodied energy. For virgin control sample and catalyzed oil samples, estimated value found to be 1.84 MJ/kg and 0.978 MJ/Kg respectively. The embodied energy involved in the production of ceramic tile and clay tile is reported as 12.0 MJ/Kg and 6.5 MJ/Kg respectively [10]. Thus,it can be safely concluded that vege roofing concept of producing tile will be environmentally friendly in terms of lower embodied energy and will help in lowering in the level of embodied carbon EC (kgCO2/kg) starting from material extraction to the final production stage of tile.

Conclusions

This study investigates the utilization of catalyzed vegetable oil for the production of tiles and concluded that catalyzed vegetable oil has the potential to substitute the conventional roofing tiles. This eco–frindely tiles found to be impermeable, showed high flexural stress and low water absorption in comparison to conventional environmentally unfriendly tiles. Moreover, electrical conductivity found to be quite low which overruled the misconception of oil leachate. Remarkably, this novel technique requires low embodied energy in contrast to conventional tiles, conserving the existing natural resources, offering a novel solution for the waste management and sustainability.

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