AN INVESTIGATIVE STUDY OF UTILIZATION OF WASTE ENGINE OIL AND VEGETABLE OIL AS A BINDER FOR THE PRODUCTION OF ENVIRONMENTAL FRIENDLY E-VEGE ROOFING TILE

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UNIVERSITI TUNKU ABDUL RAHMAN

FEBRUARY 2019

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By

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A dissertation submitted to the Department of Environmental Engineering,

Faculty of Engineering and Green Technology,

Universiti Tunku Abdul Rahman

in the partial fulfilment of the requirements for the degree of

Master of Engineering Science

February 2019

ABSTRACT

AN INVESTIGATIVE STUDY OF UTILIZATION OF WASTE ENGINE OIL AND VEGETABLE OIL AS A BINDER FOR THE PRODUCTION OF ENVIRONMENTAL FRIENDLY E-VEGE ROOFING TILE

Suubitaa A/P Spencer Sam

Knowledge of the use of recycled materials in the production of roofing tiles can facilitate the development of green technologies for building construction. The ceramic tile has the highest embodied energy and embodied carbon compared to concrete and clay tile. The mixture of waste engine oil and waste vegetable oil has been used as a binder in the production of environmental friendly roofing tiles. Impact of amount and ratio of waste engine-vegetable oil (WEVO), compaction, curing temperature and heat curing duration had been studied for the production of a new roofing tile with the materials of sand aggregates, fly ash, a catalyst, and a mixture of waste engine and waste vegetable oils. The influence of oil chemistry on extended oxidative curing had been studied by Fourier Transform Infrared (FTIR) spectroscopy, Thermogravimetric analysis (TGA) and hardness test. It was found that the presence of carbonyl functional group (C=O) is the main component responsible to bind the other materials to carry out the polymerization process to form roofing tile. The tiles were produced after being compacted and heat cured. The results showed that the tile produced using the binder from the mixture of waste engine and waste vegetable oils has fulfilled the requirements in terms of mechanical properties, durability and water permeability. The embodied energy for each WEVO Roofing tile was 0.55 MJ/kg whereas the total carbon emissions in different phases of catalyzed WEVO Roofing tile was 0.31kg CO_2/equivalent. The WEVO Roofing tiles has the lowest embodied energy and embodied carbon compared to tile composed of ceramic, concrete, clay and waste vegetable oil.

ACKNOWLEDGEMENT

With the blessings from God, I managed to complete my dissertation with the help of a number of people. First and foremost, I would like to extend our gratitude to Ministry of Higher Education for the FRGS fund with project No. FRGS/1/2015/TK06/UTAR/02/1 and Universiti Tunku Abdul Rahman for UTAR RESEARCH FUND with project No.IPSR/RMC/UTARRF/2015-C1/N02. I am sincerely thankful to my supervisor Ir. Dr. Ng Choon Aun for guiding me on how to do a proper dissertation. My supervisor showed a good cooperation, gave a considerable time and effort to accomplish this work. Guidance from my co supervisor, Dr. Chee Swee Yong and ex main supervisor, Dr. Noor Zainab Habib is highly appreciated. My appreciation also goes to my magnificent team, Humayun Nadeem and Teoh Wei Ping for the discussion relating to my research work. This acknowledgement is also for the lecturers especially Dr. Kwan Wai Hoe, Dr. Zafarullah Nizamani and Dr. Mohammed J.K. Bashir for for their willingness to share their skills, experiences and knowledge. Moreover, I would like to thank the laboratory assistants for the guidance on how to use the equipments regarding my research work. Finally, my appreciation goes to my family Vajah A/P Krishnan, Dinesh A/L Spencer Sam, Jahshni A/P Spencer Sam and Sree Shashish who have given me persistent support throughout the completion of this project.

APPROVAL SHEET

This dissertation entitled "**AN INVESTIGATIVE STUDY OF UTILIZATION OF WASTE ENGINE OIL AND VEGETABLE OIL AS A BINDER FOR THE PRODUCTION OF ENVIRONMENTAL FRIENDLY E-VEGE ROOFING TILE**" was prepared by SUUBITAA A/P SPENCER SAM and submitted as partial fulfilment of the requirements for the degree of Master of Engineering Science in at Universiti Tunku Abdul Rahman.

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LIST OF ABBREVIATIONS

Notations	Descriptions
ASTM	American Society for Testing and Materials
ASV	above-sheathing ventilation
CNSL	cashew nut shell liquid
CO_2	carbon dioxide
CTE	coefficient of thermal expansion
EPD	Environmental Product Declaration
Fe_2O_3	Iron oxide
FTIR	Fourier Transform Infrared Spectroscopy
GGBS	Ground Granulated Blast- Furnace
HDPE	High density polyethylene
HIPS	High impact polystyrene
IEA	International Energy Agency
MPa	mega-pascal
MJ/kg	mega-joule/kilogram
OPF	oil palm fiber
PBFA	palm oil fuel ash
PC	Portland cement
PFA	pulverized fly ash
POFA	palm oil fly ash
InterNachi	International association of certified home
DSC	Differential Scanning Calorimetry
UV	Ultraviolet
H_2SO_4	sulphuric acid
KWh	Kilowatt-hours
RM	Malaysian Ringgit
SEM	Scanning Electron Microscope
Si-69	silane-coupling agent
TBS	Transverse Breaking Stress
TGA	Thermogravimetric analysis
WEV oil	mixture of waste engine oil and waste vegetable oil

CHAPTER 1

INTRODUCTION

1.1 Introduction

The production of roofing tiles made from fired clay and concrete give off high levels of carbon dioxide. These types of manufacturing process hence are relatively environmentally unfriendly. The cement industry recorded about 5% of carbon dioxide emission according to International Energy Agency (International Energy Agency, 2009). Green technologies can be employed in construction sector by utilizing waste materials in the manufacturing of building materials. A survey showed that less than 0.003 percent of the 1.35 billion gallons of used oil produced annually will make it through the recycling loop in the United States (Wolfe, P. R., 1992).

Waste engine oil is disposed to the environment instead of being recycled and therefore causes harms to the marine life and human life (Bilal et al., 2003). Whereas, waste vegetable oil accumulated in the sewerage system may result in adverse environmental impact (Beddu et al., 2015). In the food production industry, particularly the commercial frying operations, about 30% of the fats and oils are discarded weekly resulting in disposal problems

(Negishia, 2003).In Malaysia, waste vegetable oil are being used 2-3 times before disposing it and 84% of the people in Malaysia dump the waste oil into dustbins, drainage system and onto the soil (Hanisah et al, 2013). Waste vegetable oil disposal means for households that do not recycle in Petaling Jaya, Malaysia is shown in Figure 1.1.

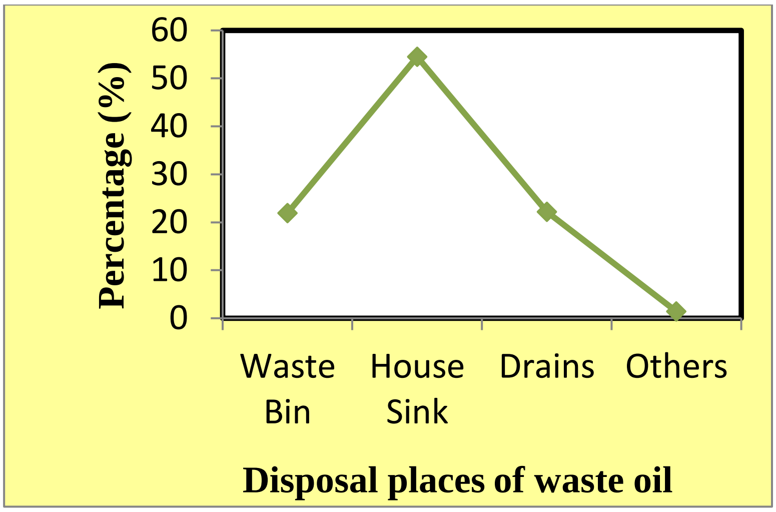


Figure 1.1 Waste vegetable oil disposal means for households that do not recycle in Petaling Jaya, Malaysia (Chen et al., 2009).

Approximately 20% of global gas emitted is from building sector. In addition, commercial cement or clay which serve as binders, contain within themselves relatively higher levels of energy and carbon (Hammond and Jones, 2011). Therefore, using used engine oil and used vegetable oil in the manufacturing of roofing tiles is found to be feasible as this can then reduce their environmental impact in return. Studies have been carried out to determine the use of oil in the manufacturing of tile made from different materials. Examples of such materials are palletized recycled high impact polystyrene (HIPS) and slate dust where different types of oils are used as binding agent (Loyd and Huddersfield, 2006). These materials are melted and run through an injection moulding process to produce composite tiles. Another study used 1% petroleum added to molten asphalts containing mineral fines to reduce viscosity of the melt for effective blending (Graham and George, 1990). This technique was used to produce roofing shingles. Other materials such as clay, a cashew nut shell liquid, oil palm fiber and formaldehyde have been used to produce tile without the usage of cement (Tiamiyu and Ibitoye, 2012). In the case of waste engine oil and waste vegetable oil, the oils were mixed in the ratio of 1:3 with the addition of ethyl cellulose powder to produce tile specimens (Sam et al., 2017).

1.2 Building Materials

Cement is commonly used as a binding material within the civil sector. Cement plants are usually built within close range of limestone quarries or other raw carbonate mineral sources. Given the sheer volume of production, mining of these materials greatly affects the environment within its surrounding. Examples of materials that needed to be mined to produce cement are calcium, silicon, aluminium and iron (Marland et al., 1999).Aside from these minerals, limestone, shells, chalk or marl which are then combined with shale, clay, slate, blast furnace slag, silica sand and iron ore are used as well (Marland et al., 1999).

Over the recent decades, researches were constantly finding suitable replacements in concrete and building materials. In order to produce a good building product, there are many issues that need to be considered. The building products usually are produced from a suitable procedure in blending the materials and time needed in blending the materials. Other issues such as the compaction rate and the curing duration can be studied as well because they can play significant impact in the production of the building materials. The materials that have been used to produce a building product need to be tested to know the suitable ratio or the type of materials used. After producing the building products, the building products are usually tested for mechanical properties such as the tensile strength and compressive strength and followed by durability or permeability based on the type of products produced. The waste materials from the industries are usually used in the production of building products. The examples of waste materials are fly ash and waste oils. The fly ash is the by product from the combustion of fuel in some industries and usually used as a replacement to cement or clay in building products. Apart from that, the waste oils such as waste vegetable oil, waste engine oil, waste petroleum oil or other types of oil can be studied properly whether they can be suitable binders in building products.

Production of these materials generates an influx of waste over time, which disrupts the balance of nature. A sustainable approach to prevent this is by re-purposing waste into a functional material by closing the production cycle loop. Careful considerations are required in planning the production cycle. Committing to the use of recycled materials and reusing materials where possible as well as utilizing locally sourced materials will reduce the influx of waste overtime. The environmental impact assessment for building materials is measured as an approximate to real environment. As with any qualitative studies the differences in observed results are caused by limits of the system considered, hypotheses applied in the assessment with regards to quality life, quality of data, end-of-life situations, energy mix and others (Ignacio, 2011). The neglecting steps in the production cycle are related to the disposal and infrastructures and considering firing fuels which are less polluting.

Though there are variances in observed results of a lifecycle assessment, they clearly indicate the impact of using such materials on the environment. To have comparison data, it is important that databases on construction materials are calibrated. One such approach would be to have public institutions encourage material manufacturers to use Environmental Product Declaration (EPD) or type III Eco labels in accordance to the ISO nomenclature which are verified by independent third parties (Ignacio, 2011).This would entail lifecycle assessment to be based on standardised information and lead to a tangible impact assessment of a building. Having this would create competition between materials manufacturers to offer new range of eco-friendly building materials as opposed to materials without any EPD.

At the end of a building's service life, it is found that different types of materials are difficult to segregate due to construction techniques that bind them. This has made recycling or repurposing building materials difficult and most of them are disposed in landfills. Besides looking at the construction materials themselves, building and construction strategies need to be studied to cater for disassembly when buildings are at the final stage of their service scenario and adhesive joints such as can be replaced by bolted joints. An overall sustainable building strategy therefore should look at ways to reduce rebound effects and enabling each capita reduction in the usage and utilization of raw materials.

1.3 Waste management

Oils were typically eliminated within the sewer system in house, industrial areas while not filter it. The waste engine oil in transports such as cars, buses, lorry, motorcycles and others are usually discarded in the rivers or lakes which can spoil the quality water due to the chemical substances present in the waste engine oil. Untreated waste engine oil affects huge volumes of water, which has detrimental significant influence on human health, marine life and plants (Bilal et al., 2003). Consequentially, this may lead to the rise of water treatment price. In addition, the inappropriate disposal of used engine oil may lead to harmful effects on human health directly (Bilal et al., 2003). Regular exposure to this type of waste oil will cause skin inflammation and provoke signs of irritancy, redness, and cracking. This is mainly caused by the presence of significant amount of heavy metal ions (Bilal et al., 2003).

Waste vegetable oil comes from the by-product of cooking using oil at a certain temperature (Beddu et al., 2015). Waste vegetable oil will produce unwanted issues to the environment if it is not discarded in correct manner. The common method of discarding used vegetable oil in Malaysia is through the kitchen sink. It results in major sewerage problems whenever the grease clogs the housing area pipes. The oil becomes rigid and firm when it chilled. The flow of the water is disrupted by the solid oil which is attached to the interior parts of the pipes. The used vegetable oil should be disposed within the proper way without harming the environment. The assumption that it is harmless to dispose of oil into the sewerage system can be partially attributed to the absence or insufficient dissemination of information supporting environmentally friendly waste management among the population.

Guidelines on proper method of discarding used cooking oil have not been established even from the manufacturers (Beddu et al., 2015). Compliance is only regulated for industrial use. As such, waste vegetable oil discarded directly in sinks ends up polluting the river and eventually polluting the entire ecosystem (Beddu et al., 2015). Once the waste gets integrated to the food chain, humans' health will be affected. Draining waste vegetable oil to the sewers can also lead to odour, taste and vermin issues. It pollutes the watercourse that is important to life. In addition, the aesthetic values of nature are inevitably reduced significantly. The existence of oil on the water surface will produce a thin coat of film and ruin the aesthetics of the water. The polluted recreational water parks will cause a reduction in the number of tourists visiting to Malaysia.

Therefore, the native economies that rely on this sector will lose the main source of income. In conclusion, it is imperative that waste vegetable oils are discarded appropriately. It is crucial to Malaysian community to be trained on proper waste management through awareness campaigns and programs on safe handling and disposal of waste oil. One of the reasons of this research is to utilize waste oil. Thus, the utilization of waste oil in the roofing tile production can generate less disposal problems to the environment. Apart from that, the oil has usually been used in building products, food manufacturing, textile manufacturing, paper manufacturing and many more. The research also includes strategies in driving an initiative to generate awareness on recycling waste oils.

Waste management is basically the organization of all processes and related to handing of waste materials. This includes collection, transportation, recycling, treatment, disposal and monitoring. Waste exists in all forms of matter whether it is solid, liquid or gas. It is also commonly classified into three main categories which are industrial, domestic and biological. These criteria's amongst others, changes the method in which the waste is handled. Waste management practices, compliance and regulation also differ globally. In fact, it even varies within a nation, for example between rural and urban areas. Apart from that, waste management allows the recovery of useful resources which normally ends up in landfills.

Landfills are designated areas such as an abandoned mining site or quarry which is used to dispose and burry waste materials. Properly maintained landfills is one of the most cost effective ways of disposing waste materials and it has been practices for decades in most countries. However, poorly managed landfills can cause major environmental impact like the attraction of vermin, wind-blown litter, and generation of liquid leach ate. Landfills emit methane and carbon dioxide as the organic waste materials biodegrades. These are greenhouses gases which prevent vegetation from growing and create an unpleasant stench. Before burying, the waste, it is first compacted to save space and it is also covered to deter pests such as rats. The methane build up could be solved using a gas extraction system.

Recycling of waste materials such as fly ash to produce a new product is found feasible instead of dumping them into the landfills.

The production of the new product by using waste materials is referred to as recycling. The reduction of energy usage is usually as a result of the use of waste materials instead of pure raw materials in the manufacturing of the new product. There are many types of recyclable materials such as paper, plastic, glass, metal, fly ash, electronics and others. The waste materials can undergo a series of processes such as sorting, cleaning and reprocessing in order to produce the new products. There are many advantages of recycling such as the reduction in cost and energy. Many types of products can be produced if abundance amount of recycling materials available in the environment.

There are many ways to raise recycling awareness among the community. The neighbourhood clean-up day can be practiced in the community where their waste materials can be collected and distributed to waste management companies. The community also can produce new products such as planter made from tyre from the waste materials. These new products can be marketed to wide range group of people. In addition, a blog can be created to share our views on how to manage waste materials. This includes such as the production of new materials from the waste materials. Therefore, the viewers can get the knowledge on how to utilize the waste materials into the production of the new product instead of disposing them to landfills. The volunteers in the community can set up recycling bins at several strategic places to encourage the people to dispose the waste materials accordingly. These strategic places usually located near to their residence so that they can dispose the waste materials. A few events related to recycling can be carried out such as the recycling campaigns at the public schools to encourage the students to practice recycling habits in their daily routines. The recycling campaigns include preparing pamphlets, banners and posters to distribute to the people. In addition, the concerns regarding the recycling can be shared at local newspaper, magazines, journal and also book, to create awareness among the people. This also can build up new investments through private business entrepreneurs to engage in waste management disposal.

1.4 Roofing tiles

The roofing tiles are used in the buildings such as hospitals, restaurants, houses and many more. The roofing tiles made up from clay or concrete have been used commonly nowadays. The main role of the roofing tiles is to protect the humans from the sun or rainy days. There are many types of designs of the roofing tiles and are usually produced from modern technology. The shape of the roofing tiles includes the Roman tiles, flat tiles, interlocking and Spanish tiles in the market. There are some tiles which are produced using heat by appropriate temperature by firing process with the materials such as shale or clay in the roofing tile production.

Tiles are produced by moulding process, pressing or extrusion. Usually the tiles produced are planner or undulating rectangular shapes which are present in different cross sectional profiles, shapes, sizes, surface, textures and colours. The ASTM C1167-03 standard specification clay roofing tiles has been followed. The specification of the clay tiles which are used as a roof covering where the durability and appearance are necessary to allow a weather resistant surface of the specified design are stated as per ASTM C1167-03. There are three grades of tiles with different degrees of resistance due to weathering effect which are covered in this specification as per ASTM C1167-03. These kinds of tiles are referred to the characteristics that have influenced on the surface as per ASTM C1167-03.

The grade of durability and type of appearance of the tiles are described as per ASTM C1167-03. Grade 1 refers to giving resistance to breakage whereas Grade 2 refers to giving resistance to medium actions. Grade 3 refers to contributing insignificant resistance towards freezing action. The types are classified to three types which are Type I, Type II and Type III. Type I is a high profile tiles with tile width ratio is greater than 1:5. Type II is a low profile tiles with ratio equal to or less than 1:5. Finally, Type III is all others tiles along with flat tiles.

1.5 Waste Engine-Vegetable Oil (WEVO) Roofing tile

A novel methodology of roofing tiles production with the binder composed of the blended oil of used engine oil and used vegetable oil with appropriate ratio. The WEVO roofing tile does not contain any form of cementitious, clay, pozzolanic materials or water. The WEVO roofing tile production is considered as environmental friendly as it can minimize the disposal of waste oil to the environment.

1.6 Energy consumptions

Embodied carbon or energy is known as the quantity of carbon or energy that has been used in the series of processes such as extraction, refining, manufacturing, logistics and the production of substances (Hammond and Jones, 2011). The emission of carbon dioxide gas is referred to as embodied carbon emission and it is important to minimize the amount of carbon dioxide in the atmosphere by practicing green technology in the construction industry. The energy emissions of processing and logistics of substances used in construction field showed about 70 percent and 15 percent respectively (Hammond and Jones, 2011). The embodied energy and embodied carbon of materials used in the construction field are shown in Table 1.1.

Table 1.1 Embodied carbon and embodied energy of materials used in the construction field (Hammond and Jones, 2011)

Materials	Embodied Energy (MJ/kg)	Embodied Carbon ($kgCO_2/kg$)
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

The ceramic tile showed the highest embodied energy and followed by clay tile, cement tile, clay brick, concrete and aggregate as per Table 1.1. The cement showed the highest embodied carbon and followed by ceramic tile, concrete, clay tile, clay brick and aggregate as per Table 1.1. The embodied energy and embodied carbon of aggregates were the lowest compared to masonry units such as ceramic tile, clay tile and cement tile (Hammond and Jones, 2008). The energy content of the substances used in the construction field can be minimized by the usage of low energy intensity substances and green technologies (Srikonda, 2012). When the energy content of the structure increased, the expected price of the structure also increased and thus, the expected energy can be evaluated. There are a few parts in the buildings that can reduce the energy in buildings such as the mud phuska terracing, channel unit roofing and filler slab roofing (Srikonda, 2012). The low price used in making the buildings is as a result of low amount of embodied energy. There are some developing countries that are showing great support on the importance of using the green technologies in the construction industry to minimize the emission of greenhouse gases to the environment and thus the reduction of embodied energy of the buildings can be obtained.

There are a few methods that can minimize the price of the buildings by having proper planning such as using current suitable substances with appropriate technology in construction for a better mechanical properties and lifespan of the buildings. The energy efficient in buildings is as a result of using the resources in a systematic ways to reduce the cost of the production of the buildings instead of using poor quality of the substances in building construction or poor works from the constructors.

There are a lot of usages of natural gas in the processing part which leads to high primary energy demand of the ceramic floor tiles. The energy value of the total usage in the production factory is as a result of the usage of klin during firing. The water used in ceramic roof tiles and bricks is lower compared to ceramic floor tiles and the primary energy can be saved when quarry tiles as averse to ceramic tiles is used for outer paving. The primary energy that has been saved is 13.45 MJ-Eq/kg which is eighty six percent and a decrease in discharge of 0.57 kg CO_2-Eq/kg which is 66% (Ignacio, 2011). The fibre cement roofs and ceramic tiles are less used in roofs compared to concrete tiles.

The primary energy demand of the light clay bricks is usually high because the energy came from the biomass. It is significant to highlight the chances for minimizing current scenarios in ceramic materials related with technological advancements in their production such as the alternative of aged intermittent kilns with tunnel kilns of an elevated efficient of energy of 20 percent, the utilization of elevated speed burners and the improvement of the hotness from the kiln smoke to dried up the materials for firing process, therefore obtaining a decrease in the usage of the kiln of 5 percent and 8 percent respectively, and the setting up of cogeneration systems with a decrease of 10 percent in the primary power (Ignacio, 2011).

1.7 Problem Statement

The existing tiles in the market such as concrete and clay tile have relatively higher embodied energy and embodied carbon which are not environmentally friendly (Hammond and Jones, 2011). Therefore, it is important to save the energy by building up tiles with good energy value. The conservation of fossil fuels and quality of environment are important factors in reducing of green house gases emission to the environment (Srikonda, 2012). The pressing issue is to find an alternative environmentally material in the production of tiles. The embodied energy in many types of tiles has been studied and evaluated. The suitable materials have been selected in the tile production with in accordance to sustainable development and energy savings. The appropriate materials and the green methods have been taken in the construction industry that is necessary in the community to enhance a positive development growth and impact to the environment (Venkatarama Reddy and Jagadish, 2003). The mechanical properties, durability and permeability of the optimized green roofing tiles have been studied. The production of building materials emits greenhouse gases such as carbon dioxide to the atmosphere. Therefore, the production of green materials has been practiced to minimize the amount of green house gases in the environment (Venkatarama Reddy and Jagadish, 2003). Adopting these practices, a hybrid binder is proposed in the production of green tiles; combining both waste vegetable oil and waste engine oil. The hybrid approach was taken as novelty under the assumptions that the combined material has additional properties to further improve singular waste oil binders.

1.8 Research objectives

The objectives of this study are as follows:

a) To optimize waste oil produced green roofing-tile in terms compositions and manufacturing processes.

b) To investigate the influence of different heat temperatures on the oil properties.

c) To investigate the mechanical properties, durability and permeability of the optimized green roofing tiles.

1.9 Research significance

The implementation of WEVO Roofing tiles is considered environmental friendly because the WEVO Roofing tile is made up from waste materials such as waste engine oil, waste vegetable oil and fly ash. Therefore, WEVO Roofing tiles can minimize the amount of greenhouse gases such as carbon dioxide to the environment. The government in Malaysia shows a great support in minimizing the greenhouse gases by setting a target in lowering the intensity of greenhouse gases up to 40% of 2005 levels till 2020 (NC2, 2011). The waste products such as waste engine oil, waste vegetable oil and fly ash have been used in the manufacturing of environmental friendly roofing tiles instead of dumping them into the environment. The outcomes of the study are to minimize the amount of greenhouse gases to the environment and the management of waste disposal to the environment.

1.10 Organization of thesis

The flow of the thesis is organized systematically to display the information to the readers. Chapter 1 shows the types of roofing tile available in the market and their high amount of greenhouse gases produced from those traditional roofing tiles. It is necessary to produce roofing tiles with reduced embodied energy and carbon. Therefore, the suitable materials have been selected to produce the WEVO Roofing tiles. Chapter 2 shows literature studies of variety of disciplines that is related to the production of environmental friendly roofing tiles. The previous works done by researchers have been studied before producing the environmental friendly roofing tiles. Chapter 3 provides the information about the materials that have been selected and the methodology of the production of environmental friendly roofing tiles. Chapter 4 provides the information of the binder of WEVO and optimization steps taken to produce the WEVO Roofing tiles. The results obtained from a few tests have been displayed in detail in chapter 4. The WEVO Roofing tile has the lowest embodied carbon and energy compared to roofing tiles made up from cement, clay or waste vegetable oil. Chapter 5 shows the conclusions that have been obtained from this study and a few recommendations have been suggested for further improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is about the studies done by researchers in the related disciplined. The materials to produce the roofing tiles such as waste engine oil, waste vegetable oil, pulverized fly ash, river sand and sulphuric acid were reviewed. The oxidative of oil was studied and reviewed too. The parameters such as curing temperature, curing duration and efficiency which are related to roofing tile and concrete have been reviewed.

2.2 A binder from waste engine oil

The waste engine oil that has been obtained worldwide was approximately less than 45% while the remaining was 55% which was thrown by the end user in the environment (Fadel *et al.,* 2003). The remaining has environmental impact because of the high cost of waste disposal and stricter environmental regulations (Fadel *et al.,* 2003). According to Chin (2012), the durability properties of concrete which act as a chemical admixture has improved when used engine oil was used in concrete as cement replacement. The tested concrete beam resulted in improved flexure characteristic (Chin, 2012). The leakage of oil into the cement in older grinding units caused production of concrete with greater resistance to freezing and thawing (Chin, 2012). The addition of an air-entraining chemical admixture to the concrete followed the similar effect (Bilal *et al.*, 2003).

Al-ghouti and Al-atoum (2009) suggested that the waste engine oil should be recycled or re-refined into pure engine oil in order to preserve the nature from harmful substances. Chin et al., (2002) mentioned that waste engine oil consists of additives and components like magnesium, polychlorinated biphenyls, zinc, arsenic, cadmium, lead, copper, chromium and chlorides. The improper disposal of waste engine oil can contaminate the groundwater and thus harms the water supply to human and living organisms (Chin et al., 2002).

2.3 A binder from waste vegetable oil

Vegetable oil has the structure as follows.

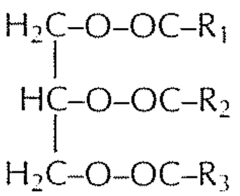


Figure 2.1 Structure of vegetable oil (Chaohua Wang and Sevim Erhan, 1999)

The hydrocarbon remaining of fatty acids consists of similar or distinct of Rl' R2, and R3 (Chaohua Wang and Sevim Erhan, 1999). The roles of the three functional groups in a triglyceride are known by the quantity of double bond that has been referred as the number of iodine and their locations (Chaohua Wang and Sevim Erhan, 1999). The cross-linked or branched of polymer occurred with the presence of groups of trifunctional (Sperling, 1992). The presence of oxygen leads to linkages of intermolecular and intramolecular in triglycerides at drying moment (Hintze-Bruning, 1993). The presence of heat leads to a reaction called as Diels-Alder (Chaohua Wang and Sevim Erhan, 1999).

A monomer can be found in the triglyceride and a dimer can be found in linkage of two triglycerides in a molecule. As the number of triglycerides increased to three triglycerides in the linkages in a molecule, it is then referred to trimer and the following subsequent is followed. The monomer, dimer or the following increment of triglycerides in the linkages in a molecule was as a result of linkage that has been referred as an intramolecular. The breakage of double bonds in a molecule by the intake of oxygen gas or the reaction of DielsAlder is related to intramolecular linkage (Chaohua Wang and Sevim Erhan, 1999). The unstable molecule in the linkage of intramolecular leads to low number of double bonds and poor cross-link (Chaohua Wang and Sevim Erhan, 1999). The low in strength is due to the reaction of the residues of the functional groups with another triglycerides and the minimization of cross-link in a system.

Vegetable oil is divided to many types such as palm oil, soybean oil, rapeseed oil, sunflower oil, coconut oil, cottonseed oil, peanut oil, olive oil and palm kernel oil (Rosillo-Calle, Pelkmans and Walter, 2009). The pure vegetable oil is utilized in a few industries such as biodiesel industry and food industry. The high demand of fresh vegetable oil is due to the high consumption of vegetable oil by the consumers, the rising national economy and the varying diets so that develop the class of living (Rosillo-Calle, Pelkmans and Walter, 2009). Waste vegetable oil is the oil that is no more used in cooking process as it is dark in colour and the oil is usually thrown away into the sinks or disposal area. The waste vegetable oil is usually collected from the food manufacturers, catering premises and domestic sources.

According to Zoorob *et al.* (2006), the production of building blocks is by blending vegetable oil with mineral aggregate followed by a process of compaction and heat curing. The VegeBlock has formed by heat curing of vegetable oil in a complex auto-catalytic oxidation and polymerisation (Zoorob *et al.* 2006). The oil component has transformed into a hard binder (Zoorob *et al.* 2006).

Banerjee et al., (2014) claims that the waste vegetable oil that has been obtained from groceries showed density of 0.91 g/cm^3 and a kinematic viscosity of 65.66 centistokes. The waste vegetable oil has to be thrown away after frequent heating due to its poor condition. The high free fatty acid and viscosity is due to degradation process (Sanli et al., 2011). The formation of dimeric and polymeric acid and glycerides occurred in waste vegetable oil due to high viscosity of the oil (Marmesat et al., 2007). The high content of free fatty acids in the oil is due to existence of water and heat which speed up the hydrolysis of triglycerides (Marmesat et al., 2007).

The substances available in the waste vegetable oil were monoglyceride, triglyceride and diglyceride (Beddu et al in 2015). The waste vegetable oil also has other substances such as saturated fatty acids which are known as stearic acid and palmitic acid (Beddu et al in 2015). Kulkarni and Dalai (2006) mentioned that the free fatty acid present in the waste cooking oil. Brown grease is the presence of free fatty acid in the waste cooking between 15% and 100% in contrast to yellow grease (Kulkarni and Dalai, 2006).

A research conducted by Sanli et al., (2011) showed that the degradation reactions for example hydrolysis, oxidation and polymerisation happened when the vegetable oil undergoes thermal treatment. The humidity available in the cooked food leads to hydrolysis whereas oxidation occurs in the presence of oxygen (Sanli et al., 2011). The increase in temperature, hydrolysis and oxidation process resulted in polymerisation process (Sanli et al., 2011).

2.4 Oxidative of oil

Lipids consist of fats and oils that undergo various chemical substances. Chemically fats and oils are triglycerides which are vital for storage lipids and the major constituents of vegetable oil and food lipids (Muik, 2005) (Vlachos, 2006). Vegetable oil that has been heated continuously during cooking can produce reactions such as the production of unwanted compounds. The examples of different kinds of transestrification are enzyme catalyzed transesterification, acid catalyzed transesterification, alkali catalyzed transesterification, acid and alkali catalyzed two step transesterification and non-catalytic conversion technique for transesterification (Enweremadu, C. C., and Mbarawa, M. M. 2009).

Acid catalyst is used when the free fatty acid content of the oil is greater than 1 wt % and the type of acids used are sulfonic and sulphuric acids due to their strong catalyst concentration and strong molar ratio which are related to corrosion matters (Enweremadu, C. C., and Mbarawa, M. M. 2009). Alkaline catalyst is used when the free fatty acid content of the oil and the water content is lower than 1 wt % and 0.5 wt % respectively and the type of alkaline used are potassium hydroxide and sodium hydroxide (Enweremadu, C. C., and Mbarawa, M. M. 2009).

The esterifying agents such as ethanol and methanol have been used in the conventional transesterification reaction however other type of alcohols can be used as well in the conventional transesterification reaction (Enweremadu, C. C., and Mbarawa, M. M. 2009). The waste vegetable oil which is used in the manufacturing of biodiesel involves the utilization of enzymes in chemical catalyzed reactions. The reaction rate can be better when supercritical alcohol is utilized in contrast to conventional transesterification as the benefits of the procedure is the whole conversion of free fatty acids to esters.

This procedure can be expensive in manufacturing companies due to use of elevated pressure, elevated temperature and good molar ratio of oil to alcohol. The engine components can require a better class of biodiesel. There are many types of downstream processing such as the segregation of biodiesel from glycerol, purification to eliminate alcohol, cleaning up of biodiesel, drying and distillation. There are many kinds of standards that have been practiced to monitor the class of the production of biodiesel.

The chromatographic procedures have been commonly used. In order to study the characteristics of the biodiesel, the tests such as pour points, viscosity, cetane number, density, calorific value, cloud and flash point have been carried out on the biodiesel. The biodiesel that are comprised of waste vegetable oil has been utilized in the diesel engines and no amendments are needed in the engine as the fuel characteristics of the biodiesel has fulfilled the standards required at national level.

There are many procedures need to be carried out by using instruments on the vegetable oil which acts as a binder by heat curing the vegetable oil at required temperature to obtain the characteristics of the vegetable oil. The mechanical characteristic of the material is influenced by the reactions that are produced in material by the factor of curing duration. The curing duration can play important role in the reactions produced by the use of vegetable oil in the material. The stability of volumetric and gravimetric results of waste vegetable oil can show that the binder composed of waste vegetable oil has an impact on curing duration by porosity, choosing of material and grading.

The isomerisation process can be determined in situ in vibrational spectroscopy besides the absence of cis double bonds (Heaton et al., 2014). The spectral overlap is unseen for the production of hydroperoxide and the following decomposition (Heaton et al., 2014). There are a few types of secondary oxidation products like ketones, aldehydes and epoxides which is similar to all products besides the absence of fatty acid chains from whole TAGs (Heaton et al., 2014).

It is important to outline the few parts in the chemistry related to the procedures in the production of the materials. The production of volatile products, oxygenated monomeric and cross-linked are produced at the reactions involving double bonds during curing process (Heaton et al., 2014). The curing process which is related to heat and oxidative environment might be involved in the reactions with secondary oxidation products such as ketones, aldehydes and epoxides (Heaton et al., 2014). The products might carry out reactions at room temperature during storage. The waste vegetable oil has been blended with waste products and undergoes heat curing process for free radical oxidation reactions.

Zahir et al., (2014) mentioned that distinct spectral band was obtained after tested with FTIR spectroscopy for high temperature frying oil. FTIR analysis showed that the quality of oil decreased after being heated frequently (Zahir et al., 2014).In order to characterize the thermal stability of a substance, TGA method was used by determining the differences in its physicochemical properties (Coats ans Redfern, 1963). According to pencil hardness test, the major factors for improved pencil stratch resistance are intrinsic hardness of the coating material, elastic modulus, fracture toughness and layer thickness (Wu et al., 2008).

2.5 Pulverized fly ash (PFA)

Pulverized fly ash (PFA) is actually a residue that is retrieved from the burning of coal at power stations under certain appropriate temperature. Pulverized fly ash (PFA) composed a few types of substances such as aluminium oxide, silicon oxide and iron oxide (Baljeev et al., 2012). Since the fly ash is an unwanted material, the fly ash is usually thrown in landfills. As the amount of fly ash keep on accelerating at the landfills, it becomes a threat to the environment. Therefore, the fly ash is usually used in manufacturing of products such as building products, polymers and many more. Thus, the amount of disposal of fly ash in landfills can be minimized and shows a positive impact to the environment.

The treating of fly ash is vital as it can be blended well with polymer such as High density polyethylene (HDPE) to produce the lightweight composites (Baljeev et al., 2012). The lightweight composites composed of fly ash and polymer showed good strength after testing in terms of mechanical properties and durability (Baljeev et al., 2012). The economic evaluation of the lightweight composites comprised of fly ash and polymer is affordable as the fly ash is a waste product (Baljeev et al., 2012).

There are many research works related to the use of fly ash as building materials. The fly ash has been studied in three distinct ways such as the amount of fly ash, concentration of fly ash and the particle size of fly ash in the production of building product (Ahmad and Mahanwar, 2010). There was an increment in mechanical properties after the increase of fly ash in the composition (Ahmad and Mahanwar, 2010). However, a reduction was noticed for the impact resistance and tensile elongation after the increment in the concentration of fly ash (Ahmad and Mahanwar, 2010). The relative elongation and strength were good in the tiny size of particle of fly ash (Ahmad and Mahanwar, 2010). However, the particle size of fly ash did not influence the impact resistance and modulus (Ahmad and Mahanwar, 2010). The injection molding technique was used on the prototypes and the twin screw extruder was used to make the composites (Ahmad and Mahanwar, 2010).

Thermo Haake Rheomixer is used to make the composites that composed of the mixture of fly ash, calcium carbonate and used high-density polyethylene (HDPE) (Atikler et al. 2006). The fly ash was treated with amino propyl triethoxy silane to enhance the strength of the composites (Atikler et al. 2006). The Pukanszky model and the observation of the structure from Scanning Electron Microscopy (SEM) revealed that the composites have good interfacial adhesion if treated with silane (Atikler et al. 2006).

In order to produce the lightweight composites, the material such as the Fly ash Cenospheres was utilized in High Density

Polyethylene (HDPE) (Deepthi et al., 2010). The residue or the unwanted material of the combustion procedure at thermal power plants is referred to Cenospheres (Deepthi et al., 2010). In order to minimize the load of materials such as cements, rubbers and many more have been used for oil drilling method as a filler in lubricants with strong stress environment and thermal heat at the bottom of the opening Cenospheres (Deepthi et al., 2010). The materials such as the Phenolic resins, plastisols, Latex, Polyesters, Epoxies, urethanes and thermoplastics were easily to blend with the Cenospheres (Deepthi et al., 2010). The decreased in load, increment in substituent loadings, good flow properties, low in shrinkage and warping and a decrease in water absorption were among the positive impact of the use of Cenospheres (Deepthi et al., 2010). The strength and the heating characteristics of the lightweight composites which were followed in accordance to ASTM showed a progress by the alteration of the exterior of the Cenospheres (Deepthi et al., 2010).

In order to produce the lightweight polymer composites, the Fly ash Cenospheres was utilized because the Fly ash Cenospheres had a load minimizing substituent and a good economic evaluation (Chand et al., 2010). The progress of the strength of the base polymer matrices had an impact due to the use of the Cenospheres (Chand et al., 2010). Thehomogeneous distribution of Cenospheres and a good relationship of matrix of polymer and the Cenospheres showed an impact on the preferred development (Chand et al., 2010). The alteration of the exterior of the Cenospheres with use of a treatment of silane and including them in a flexible thermoplastic high density polyethylene were due to the development of the composites in terms of the density or the influence of mechanical properties (Chand et al., 2010). The treat using silane for the strength characteristics and wear resistance was consistent to the composites that undergo the silane treatment compared to without the silane treatment for the Cenospheres which can be described as the correlation of Lancaster–Ratner (Chand et al., 2010). In order to determine the wear approaches and methods, the Scanning electron microscopy and X-ray diffractograms equipments were selected (Chand et al., 2010).

The palm kernel nut shell and the High Density Polyethylene (HDPE) were utilized in the composite to study their strength characteristics (Ishidi et al., 2010). The machine of Carvers Hydraulic Hot Press and Reliable Two Roll Mill Model 5183 were used for the substances to be compounded and produced (Ishidi et al., 2010). According to the standard following the ASTM standard specifications, the testing methods were carried out on the optimized composites (Ishidi et al., 2010). The composite was tested to determine their water absorption percentage level (Ishidi et al., 2010). The tensile characteristic was experiencing some modification with the presence of filler based from the data retrieved from the study (Ishidi et al., 2010).The increment after the presence of filler was influenced by the increment in their mechanical properties (Ishidi et al., 2010).The reduction in the tensile strength occurred with the use of strong load of filler (Ishidi et al., 2010).The increment in the presence of filler was influenced by the rigidity of the composite and the increment in water absorption percentage as well as the effective relationship of matrix and filler according to Environmental Scanning Electron Microscope (ESEM) (Ishidi et al., 2010). The filler that was treated with alkali such as sodium hydroxide resulted in the good relationship between the filler and matrix (Ishidi et al., 2010).

The composites composed of the High Density Polyethylene (HDPE) which comprised of filler of fly ash showed good coefficient of thermal expansion (CTE) and thermal conductivity (Biglari and Kole, 2011). In order to develop good thermal conductivity and thermal stability of the composites, the fly ash in HDPE was utilized (Biglari and Kole, 2011). The increment of amount of fly ash resulted in the high amount in HDPE but a reduction in CTE (Biglari and Kole, 2011). There were variety of theoretical models to determine the CTE and the thermal conductivity and CTE of the composites composed of the High Density Polyethylene (HDPE) which comprised of filler of fly ash (Biglari and Kole, 2011).

The injection moulding machine was used in the production of a composite composed of ceramic and polymer (Saude et al. 2012). The High Density Polyethylene (HDPE) powder comprised of palm oil fly ash (POFA) (Saude et al. 2012). The matrix substance was influenced by the palm oil fly ash (POFA) (Saude et al. 2012). The compositions of ratio of blending with many types of ceramic and polymer composite had been studied (Saude et al. 2012). The mechanical properties such as the rigidity and the flexural strength were influenced by the high amount of palm oil fly ash (POFA) used (Saude et al. 2012). In order to fabricate the composite composed of ceramic and polymer, a progress in reusing the waste products had been practiced (Saude et al. 2012).

The steps to prepare the composite composed of fly ash and the properties of the composite composed of fly ash and the melt mixing of unwanted product such as polyethylene was retrieved polyethylene (WPE) in distinct ratios (Satapathy et al., 2010). The mechanical characteristics of the mixture and composites had been studied with or without the use of silane-coupling agent (Si-69) and the mechanical characteristics were progressed with the use of silane-coupling agent (Si-69) (Satapathy et al., 2010).

In order to produce the stress-strain curves, the compressive characteristics of roof tiles with its compositions had been studied (Mohammad et al., 2004). The mechanical properties of the roof tiles showed an improvement when the fly ash was blended with unwanted polythene Fibre (Mohammad et al., 2004). The roof tiles showed good energy value and the roof tiles can minimize the environmental problems such as minimizing the amount of carbon dioxide gas to the atmosphere (Mohammad et al., 2004). The waste materials that had been used to produce roofing tiles can reduce the waste disposal problems to the environment (Mohammad et al., 2004). The blending of the polythene fibre showed a great influence on the mechanical properties of the tiles (Mohammad et al., 2004). The roof tiles are water resistance due to the use of polythene fibre which can enhance the mechanical properties of the roof tiles (Mohammad et al., 2004). The water cannot penetrate the roof tiles as it was water resistance (Mohammad et al., 2004).

The roof tile that was made up from clay had a higher cost compared to the roof tiles composed of fly ash (Mohammad et al., 2004). The fly ash can be obtained free of charge and fly ash present at any plant power station that undergoes the process of combustion of fuel (Mohammad et al., 2004). The usage of unwanted polythene fibre can minimize the hazardous impact because the unwanted polythene fibre prevents the mixing of the soil with the water source (Mohammad et al., 2004). The water absorption was low for the roof tiles made up with fly ash. The low usage about 15 percent and below was used for the mortar (Mohammad et al., 2004).The low cost of the roof tiles were due to proper management and logistics (Mohammad et al., 2004). The roof tile that was made up of fly ash had been used in construction because it had a good workability and quality compared to roof tiles that were made up of clay (Mohammad et al., 2004).

2.6 Related work on roofing tile

A roof acts as a shield from the rain, sun, and wind. It is created to limit or avoid the flow of energy and mass, associated on the environmental changes between the outdoor ambient and the conditioned space for example the outside weather and the roof deck. The concrete roofing tiles and clay roofing tiles are usually referred as the conventional roofing tiles (Miller et al., 2005).

It is essential to keep good airflow and heat dissipation in the roof deck to maintain a comfortable indoor environment. Thus, a durable and energy efficient roofing design is needed. Over the years, craftsmen have learned through practical regulation of experience and keen understanding of materials and have advanced the design and substance properties of roofing materials. One key observation was on how overlapped slates and stone slabs have water dissipating quality. Though natural slabs have this quality, clay was preferred for its moulding capability. The early clay tiles were hand-made and were moulded over thighs of female artisans. This gave them a distinctive concave shape which tapered such as wide at one end and narrower towards the other (Baker 1980). This was the first single-lap roof tiles and can be seen to date in some Spanish tiles. The chance discovery of this novel design produced unexpected results in the durability of roofs and enhanced its energy efficiency.

The single-lap design accompanied by the use of plywood as roof decking material creates and air-space through which air passes through and creates a lane for natural ventilation (Rose 1995). In order to have good air passage underneath the roof, the building of counter-batten is practiced to give the gaps of air on the outside of the roof sheathing and the inner of the roof cover. The heating characteristic is good when the materials such as stone-encapsulated metal roofs and tile are located on counter-batten and batten. However, the technique is not used in places like California or Florida due to storms that can cause wind uplift (Rose 1995).

In order to eliminate the heat and moisture from the roof deck, this scheme of ventilation is practised and results in enhancing the heating characteristics and the durability of the roof as studied by Miller, Wilson, and Karagiozis (2006). The exterior of the roof is irradiated by solar energy and gives off heat which in turn heats the air above the roof tiles. Due to the buoyant effect of warm air, the air rises creating a circulation of warm and cold air. This contributes to the heat dissipation and air circulation which removes moisture. This also effects the ventilation between the roof sheathing and the roof tiles. This is referred to as above-sheathing ventilation (ASV) which is an air-space that has thermally induced air flow (Miller et al., 2005).

Profiles of roofing tiles also contributed to its heat dissipating characteristics. The least amount of heat to break in into roof decks are observed with tiles with high profiles as is with the case of the S-Mission tiles (Miller et al., 2005). A study comparing the clay S-Mission tiles and asphalt shingles showed that the clay tile (SR54E90)2 had lesser heat going into the ceiling of an attic by up to 60% and had the smallest heat flux across the roof deck (Miller et al. 2005).

Solar reflectance and thermal emittance of the materials were studied as well. Both the solar reflectance and the thermal emittance for asphalt shingle (SR10E89) were observed to the same when compared to a slate concrete roof (SR13E83) and a medium-profile concrete tile (SR10E93) (Miller et al., 2005).However, the transfer of heat via the roof to the ceiling of the attic were 50 percent of the asphalt shingle roof in comparison (Miller et al., 2005). This reduction in value of heat transfer is primarily due to the thermal mass of the materials and the inclined air pathway which is contributed by the profile of the tile (Miller et al., 2005).

Concrete roofing tiles consist of sand, cement and water and the production of roofing tiles is at room temperature. Therefore, the concrete roofing tiles are considered as a green roofing tiles and good for the environment. International Energy Agency stated that the emission of carbon dioxide from the industry that is producing cement is about 5 percent (Tanaka, 2009). About 0.81 kg of emissions of carbon such as carbon dioxide gas is produced from 1 kg of cement

(Huntzinger and Eatmon, 2006). The use of energy resources is common in the building construction industries and the dangerous substances are expelled when the energy resources are utilized in construction field (Huntzinger and Eatmon, 2006).

Apart from that, the bi-product of manufacturing cement can cause acute and chronic health issues such as asthma, severe cough, allergy and vision impairment (Marland et al., 1999). This study shows that the cement binder will be substituted with a waste material such as waste vegetable oil and waste engine oil. Han et al. (2013) investigated the impact of waste engine oil on the capability to withstand high volume admixture concrete. There are many types of binders in building that are used such as cement, dry bricks , mortars, lime and many more (Han et al. 2013).The minimum temperature used in the production of clay tiles is 1000°C at about 1 to 3 days of firing in a klin. The method requires emissions of approximately 1.84–2.8 kJ/kg of energy and the 184–244 kg of carbon dioxide per tonne of tiles (Forth and Shaw, 2013).

According to Humayum et al., in 2017, the catalyzed Vege-roofing tiles showed flexural stress of 12 MPa for 18 hours of curing. The catalyzed Vege-roofing tiles composed of used vegetable oil, a catalyst, sand and filler (Humayum et al., 2017). A complex oxy-polymerisation reaction occurred when the used vegetable oil turns into hard binder (Humayum et al., 2017). The embodied carbon and embodied energy for the roofing tiles were 0.327kg carbon dioxide per equivalent and 0.64 MJ/kg (Humayum et al., 2017). Therefore, these roofing tiles were considered to be cost efficient and good for the environment (Humayum et al., 2017). According to Zoorob et al (2006), the production of Vegeblocks using vegetable oil by suitable selection of materials, adequate compaction and heat curing, compressive strengths exceeding 25 MPa are achievable.

According to Tiamiyu and Ibitoye in 2012, the productive roofing tiles were produced when the composites composed of clay content in the ranges of 30 until 35 wt%. The overall materials in the production of OPF-CNSL-formaldehyde roofing material were clay and a cashew nut shell liquid (CNSL)-formaldehyde was reinforced with oil palm fiber (OPF) to produce six experimental mixes (Tiamiyu and Ibitoye, 2012). The composites were produced from each mix with 0.25 wt% OPF by hand lay-up approach and compression molding (Tiamiyu and Ibitoye, 2012).

In order to mitigate the degradation by the cellulose fibres in the low aggressive medium, the use of accelerated carbonisation was implemented (Tonoli et al., 2010). In addition, the accelerated carbonisation showed good effect on the mechanical and physical characteristic of the roofing tiles (Tonoli et al., 2010). The type C of fly ash was mixed with distinct substances as a clay replacement in order to produce fly ash roof tiles (Mohammad et al., 2014). In addition, the roof tiles composed of fly ash showed good compressive strength and economical compared to the use of clay in the production of roof tiles (Mohammad et al., 2014). The optimum results of Transverse Breaking Stress (TBS), density, permeability and water absorption were obtained at 15% rice husk ash and at temperature 900°C in the manufacturing of clay roof tiles (Raheem et al., 2015).

Alavez-ramirez et al., (2014) mentioned that the surface temperature of roofing tile was obtained by using thermocouple sensors shielded with direct solar radiation and room temperature. Temperature readings were recorded for each 30 minutes for 12 months (Alavez-ramirez et al., 2014).

2.11 Related work on concrete

The corrosion of reinforced concrete (RC) structures in aquatic nature is due to Chloride-induced corrosion of carbon steel reinforcement (Val and Stewart, 2003). The corrosion-resistant stainless steel reinforcing bars is utilized to maintain the RC structures from deterioration (Val and Stewart, 2003). The carbon steel is cheaper than stainless steel therefore the life-cycle cost basis is studied. In order to determine the life-cycle costs for RC structures in aquatic surroundings at distinct exposure nature, the time-variant probabilistic model was applied to forecast the estimated cost of maintenance and substitution (Val and Stewart, 2003). In order to choose the optimal techniques to upgrade durability of RC structures in aquatic nature and the utilization of stainless steel reinforcement, the life-cycle cost analysis is studied (Val and Stewart, 2003).

Buildings has high energy usage in their life cycle beginning from its construction to destruction. Results present that operating (80–90%) and embodied (10–20%) stages of energy use are important contributors to building's life cycle energy demand (Ramesh et al, 2010). According to Ramesh et al in 2010, the life cycle energy (primary) requirement of conventional housing buildings showed the range of 150–400 kWh/m2 per year and the workplace buildings showed the range of 250–550 kWh/m2 per year. Building's life cycle energy usage can be minimized by reducing its operating energy via active and passive techniques (Ramesh et al, 2010). Analysis has recorded that reduction in energy buildings show better than self-sufficient (zero operating energy) buildings in the life cycle context (Ramesh et al, 2010).

According to Swaroopa Rani and Tejaanvesh in 2015, the supplementary cementitious material such as Palm Oil Fuel Ash (POFA) has been used partially as cement substituent in high strength concrete. A crack can be avoided after the addition of supplementary cementitious materials in high strength concrete due to low heat of hydration and low shrinkage (Swaroopa Rani and Tejaanvesh, 2015). The mechanical properties such as comprehensive strength, flexural strength and split tensile strength of concrete mix of M60 grade showed an improvement with substituent of cement up to 15% in high concretes (Swaroopa Rani and Tejaanvesh, 2015).

Amer et al., (2015) stated that the increase in curing duration resulted in high compressive strength for palm oil fuel ash geopolymer pastes. The compressive strength of palm oil fuel ash geopolymer pastes was high at 70°C compared to room temperature, 60°C and 80°C (Amer et al., 2015). Therefore, the curing process was suitable at temperature of 70°C (Amer et al., 2015). According to Olalekan et al., (2014), the base substances oxide samples and activators ratio influence the curing efficiency. According to Amer et al., (2015), the hardening time decrease when the temperature was increased after room temperature for palm oil fuel ash geopolymer pastes.

According to Mojtaba Vainejad Shoubi et al., in 2013, the concrete is expected to be the crucial material that have been utilised broadly in the construction field. The manufacturing on Portland Cement (PC) which has been a compulsory form of concrete resulted in hazardous effect towards the earth through excessive emission of carbon dioxide (Mojtaba Vainejad Shoubi et al., 2013). Moreover, the carbon dioxide gas is one of the components of green house gases which cause global warming (Mojtaba Vainejad Shoubi et al., 2013). The carbon dioxide emissions stage for Portland cement is approximately one ton per ton (Mojtaba Vainejad Shoubi et al., 2013).

The sustainable development can be achieved by the low consumption of cement or substituting cement with other materials (Mojtaba Vainejad Shoubi et al., 2013). The research in cement replacement products such as pulverized fly ash, Ground Granulated Blast –Furnace (GGBS) and silica fume has been carried out for green technology in the environment (Mojtaba Vainejad Shoubi et al., 2013).

According to Beddu et al., in 2015, the green materials are being used in construction field. Waste cooking oil has been used as admixture in concrete. The concrete that contains the waste cooking oil showed good mechanical properties, high in workability and reduction in interfacial transition zones and air voids size compared to control mix (Beddu et al., 2015). Waste cooking oil which acts as a lubricant for concrete has improved flexural strength and compressive strength when compared to control mix (Beddu et al., 2015).

According to Johnson Alengaram et al., in 2008, a grade 35 lightweight concrete has been produced with the consumption of palm kernel shell .The 5% of fly ash and 10% of silica have been added in the cementitious materials (Johnson Alengaram et al., 2008). A concrete density of 2000 kg/m^3 was achieved at high sand to cement ratio beyond 1.6 (Johnson Alengaram et al., 2008). A good compressive strength and density are influenced by sand content (Johnson Alengaram et al., 2008). Other tests that had been carried out were modulus of elasticity, flexural and splitting tensile strengths. A cohesive mix was obtained with the presence of silica fume (Johnson Alengaram et al., 2008).

According to Nasir Shafiq et al., in 2011, the agricultural residues and industrial by-products have been used as a cement substituent in concrete. The characteristics of fresh and hardened concrete containing waste engine oil have been studied (Nasir Shafiq et al., 2011). There were no significant changes of the comprehensive strength of the concrete but an improvement was recorded in air content and concrete slump compared to the control mix (Nasir Shafiq et al., 2011). A reduction was noticed in oxygen permeability and porosity of the concrete (Nasir Shafiq et al., 2011). The fresh engine oil and waste engine oil showed almost similar effect in concrete (Nasir Shafiq et al., 2011).

According to Chin et al., in 2012, the use of industrial by-products in cement and concrete shows a positive influence to the environment and economic. An improvement of capacity was recorded for ordinary Portland cement (OPC) and ordinary Portland cement with rice husk ash reinforced concrete beams with waste engine oil and super plasticizer compared to control mix (Chin et al., 2012). The crack patterns of reinforced concrete (RC) beams and the load deflection behaviour have been studied (Chin et al., 2012). A decrease in capacity was shown by fly ash concrete beams with admixtures compared to control mix (Chin et al., 2012).

According to Swaroopa Rani and Tejaanvesh in 2015, the supplementary cementitious material such as palm oil fuel ash (PBFA) has been used partially as cement substituent in high strength concrete. A crack can be avoided after the addition of supplementary cementitious materials in high strength concrete due to low heat of hydration and low shrinkage (Swaroopa Rani and Tejaanvesh, 2015). The mechanical properties such as comprehensive strength, flexural strength and split tensile, strength of concrete mix of M60 grade showed an improvement with substituent of cement up to 15% in high strength concretes (Swaroopa Rani and Tejaanvesh, 2015).

According to Hesham Diab in 2011, the compressive strength of the concrete contained waste engine oil decreased in high strength and low concrete. The cloudless was observed in the aggressiveness of oil for high strength and low concrete (Hesham Diab, 2011). The compressive strength was influenced by the degree of oil saturation (Hesham Diab, 2011). The behaviour of concrete containing oil or without oil showed the aggressiveness of the oil (Hesham Diab, 2011).

According to Kunhanandan Nambiar and Ramamurthy in 2006, the filler such as fly ash and sand affect the characteristics of the moist cured foam concrete. A greater ratio of strength to density was achieved by fly ash than sand (Kunhanandan Nambiar and Ramamurthy, 2006). The strength of the foam was improved by the small particle size of the sand (Kunhanandan Nambiar and

Ramamurthy, 2006). The characteristics such as flow behaviour, strength, density and water absorption were studied (Kunhanandan Nambiar and Ramamurthy, 2006).

A few parameters have been studied before conducting the research work. The materials to produce the roofing tiles such as waste engine oil, waste vegetable oil, pulverized fly ash, river sand and sulphuric acid were reviewed to determine their physical and chemical properties. The oxidative of oil was studied and reviewed to determine the characteristics of the oil after heat curing. The parameters such as curing temperature, curing duration and efficiency which are related to roofing tile and concrete have been reviewed to determine the suitable conditions for the production of green roofing tile. The hybrid combination of two different waste oils is proposed to further improve tile properties and reduce carbon footprint. Both waste vegetable oil and waste engine oil are commonly available and has good binding properties.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

This chapter shows the plan and methods taken to achieve the objectives for this research work. The collection of raw materials, optimization of parameters and production and testing of optimized products are stated in this chapter. The energy characteristic and cost of the tiles have been calculated. The binder selection makes up of waste engine-vegetable oil (WEVO). Binders' specifications in terms of rheology and oxidative curing were also performed. The physical properties of pulverized fly ash, river sand and catalyst have been studied. The manufacturing process of WEVO Roofing tile is done after obtaining the suitable parameters for optimization process. The laboratory investigation of WEVO has been performed by Fourier Transform Infrared Spectroscopy (FTIR) analysis, Thermo gravimetric analysis (TGA), hardness test and Scanning Electron Microscope (SEM). The testing of the tile has been performed by flexural strength, water absorption and water permeability.

3.2 Materials

The materials to produce the roofing tiles such as waste engine-vegetable oil (WEVO), pulverized fly ash, river sand and sulphuric acid had been used.

3.2.1 Waste engine-vegetable oil (WEVO)

WEVO which is dark brown in colour has specific gravity, density and kinematic viscosity of 0.90, 0.91 g/cm^3 and 65.87 centistokes respectively. WEVO is composed of saturated fatty acids such as stearic acid and palmitic acid and followed by monoglyceride, triglyceride, diglyceride.

3.2.2 Pulverized fly ash (PFA)

The type of fly ash used was class F fly ash which is light brown in colour with the size about 75µm.Fly ash was retrieved from TNB power plant station in Manjung, Setiawan, Perak, Malaysia. The chemical components in fly ash are silica, alumina, magnetite and Fe_2O_3 (Iron oxide). The spherical fly ash had a specific gravity and specific surface area in between 2.5 and 200 m^2/kg respectively. The amount of fly ash used to produce bricks in China (Lingling et al., 2005) is in between 10% and 30%.

3.2.3 River sand

The river sand which is white in colour was obtained from mining area in Kampar. The river sand was transferred into a tray and kept in an oven for 2 hours at 150°C. River sand which had the size between 63 and 177 μm had specific gravity, density and water absorption of 3.1, 2620 kg/m^3 and 0.81% respectively. River sand composed of andalusite and tourmaline. The moisture content of the river sand is 3.4% and the sand was sieved. The size gradation of aggregates was carried out accordingly (ASTM C 136, 2014). Sieve analysis was employed for the particle size distribution of sand aggregates. For each sieve analysis, 1 kg of sand was utilized and sieves are with the size of 3.35 mm, 2.36 mm, 1.18 mm, 0.425 mm, 0.3 mm, 0.212 mm and 0.15 mm respectively. Sieve analysis was conducted with coarsest sieve at the top and the finest sieve at the bottom. The percentage of passing of fine aggregates was highest in 3.35 mm sieve which is the coarsest sieve in the analysis as per Table 3.1. It was found to be least from the finest sieve of size 0.15 mm as per Figure 3.1.

Table 3.1 Size gradation of river sand (ASTM C 136)

Sieve Size (mm)	Weight Retained (g)	Weight Retained (%)	Cumulative % Retained	Total Passing (%)
3.35	7	0.7	0.7	99.3
2.36	20	2	2.7	97.3
1.18	321	32.1	34.8	65.2
0.425	345	34.5	69.3	30.7
0.212	195.8	19.58	88.88	11.12
0.15	21	2.1	90.98	9.02

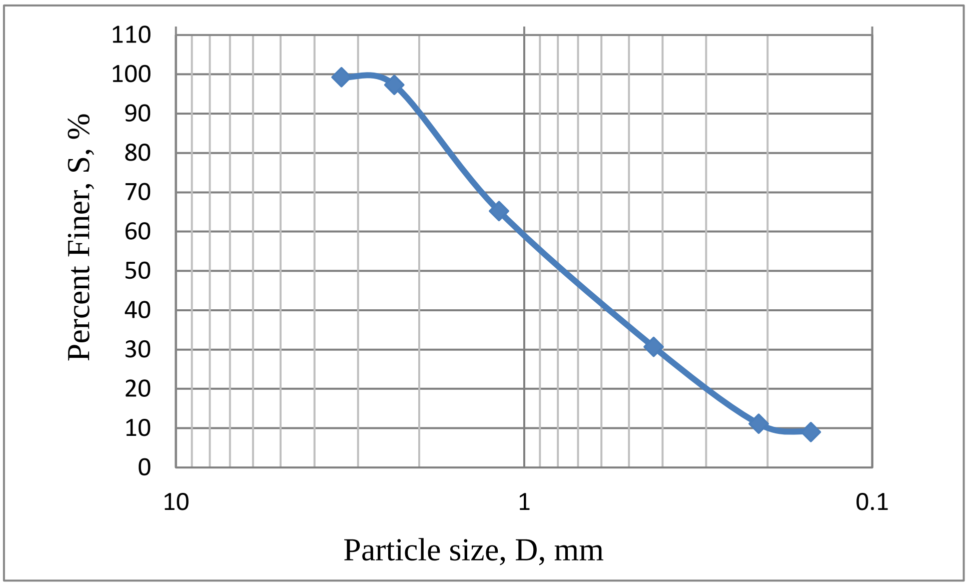


Figure 3.1 Particle size distribution curve of river sand

3.2.4 Catalyst

Sulphuric acid had been used as a catalyst and it was colourless. When acid waste oil is used, the transesterification reaction and direct esterification reaction occurred (Marchetti and Errazu, 2008).The sulphuric acid was added in the WEV oil to enhance transesterification reaction and direct esterification reaction to speed up the rate of reaction for the tile formation.

3.3 Manufacturing process of WEVO Roofing tile

The used engine oil and used vegetable oil retrieved from local car station and restaurant respectively were mixed with a rotary shaker at 250 rpm for 20 minutes with a ratio of 1:4 respectively. The ratio was selected due to strong presence of carbonyl in waste vegetable oil compared to waste engine oil by FTIR analysis and also availability to obtain the oils. The formulation and composition of the different substances for experimental mixes of T1 to T6 are shown in Table 3.2. The amount of 0.1 percent of sulphuric acid was added in the WEVO to form catalyzed WEVO. The mixing of the materials such as catalyzed WEVO, fly ash and river sand had been done at about 250 rpm at room temperature for 10 minutes by a mixer. 81% of river sand has been used in the production of tile composed of ethyl cellulose and waste oil (Sam et al., 2017). The mixture with the weight of 400 gram was transferred into the mould and compacted with a compactor in the range of 5 to 20 of compaction counts. The compacted mixture was placed into the oven for heat treatment at the temperature in between 100°C and 200°C for 1 to 24 hours. Each compaction count represents 7.567 kN. The specimen with 100 mm diameter was left to cool down. The starting preferred values of the parameters for the optimization step had been referred to the previous studies of the researchers and trial and error method as per Table 3.3. WEVO Roofing tile was produced after obtaining the suitable parameters to produce the tiles. The experiment was repeated for five times for accuracy and average data was recorded. The tiles were tested for mechanical strength, durability and water permeability. The methodology flowchart was shown in Figure 3.2.

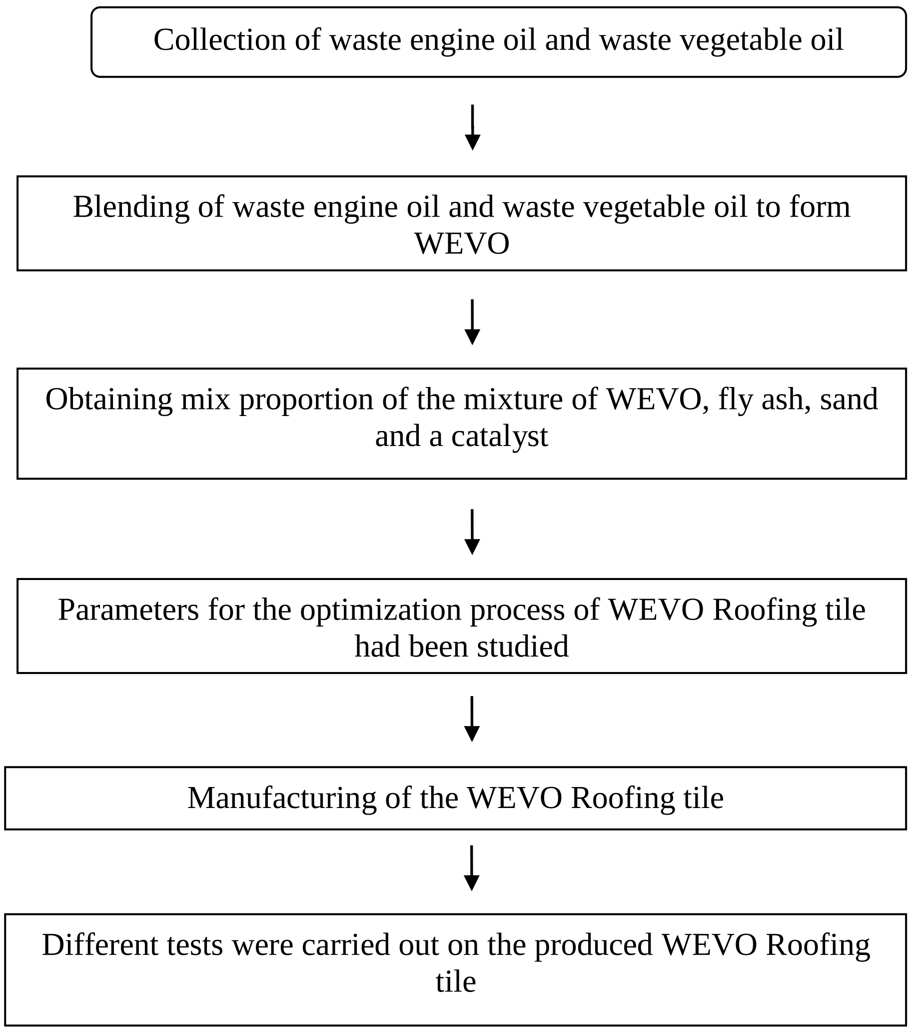


Figure 3.2 The process of production of WEVO Roofing tile

Table 3.2 Formulation of experimental mixes

Raw materials	Composition (wt. %)					
	T1	T2	T3	T4	T5	T6
Sand aggregates	81	81	81	81	81	81
Fly ash	18	17	16	15	14	13
Catalyzed WEVO	1	2	3	4	5	6

Table 3.3 Starting preferred selected values of parameters for the optimization step

Optimization sequence	Parameters	Preferred
1[a]	Amount of WEVO	1-6%
2	Ratio of WEVO	0.25, 0.33, 0.5, 1, 2, 3, and 4
3	Compaction method	Manual or machine compaction
4[a]	Curing temperature	100°C-200°C
5[a]	Curing duration	1-24 hours

[a]Forth and Zoorob (2013)

3.4 Laboratory investigation of WEVO

3.4.1 Fourier Transform Infrared Spectroscopy (FTIR)

Infrared spectra of the waste oils were determined with PerkinElmer Spectrum FTIR RXI spectrometer. FTIR spectroscopy was also used to determine the molecular structures via some absorption bands that are associated to the functional groups of the compounds (Ullah, 2014). The samples were scanned over a region of 400 until 4000 cm^{-1}.

3.4.2 Thermogravimetric analysis (TGA)

TGA is a technique for characterizing the heat stability of a substance (Coats and Redfern, 1963). Thermal behaviour of the waste engine-vegetable oil was determined by Thermogravimetric Analyzer model (METTLER TOLEDO TGA,SDTA851e) from 25°C and 500°C at heat flow (mW) 10°C/min under 10 ml per minute of nitrogen purge.

3.4.3 Hardness test

Hardness test was considered as one the useful techniques for the selection of catalyst with waste oil in the production of tiles. Oil films produced from an equal amount of each mixture's blend were baked at distinct temperatures and varying curing times and their gouge hardness demonstrated according to standard hardness test (ASTM D 3363). WEVO was heat cured at 1 hour until 24 hours at 190^0C to understand the oil binding mechanisms at prolonged curing durations. The preferred temperature for the baking of each oil film during pencil hardness test at 24 hours was studied.

3.4.4 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) was carried out to determine the morphology of the tile composed of WEVO. The plate which contained the tile composed of WEVO was inserted into the SEM machine (Jeol, JSM-6701F) and tested.

3.5 Testing of the tile

3.5.1 Flexural strength

The tile was placed on Universal testing machine of Instron 4469 as per Figure 3.3 to obtain the flexural strength of the tiles. Flexural strength of the specimens was calculated by using the equation as follows.

σ= MC/I

where,

M= bending moment in Newton

C=distance from the neutral axis in millimeters

I=moment of inertia in millimeters

Flexural stress was calculated by means of standard method (ASTM C 67-13; ASTM C 1492-03). Flexural stress for standard roofing tiles can be calculated by using the following equations:

$\sigma = 3*P*L / 2*W*d^2$

where,

σ= Flexural strength in MPa

P =Loading force in Newton

L = Span Length of the tile

W = Width of the tile

d = Thickness of the tile

Figure 3.3 Universal testing machine of Instron 4469

The influence of ultraviolet on the tiles was determined by locating the tiles inside the ultraviolet chamber. The tiles were sprayed with water five times a week to imitate the real environment of open air. The tiles were exposed to UV radiations and saturated conditions for 900 days and the tiles were tested for their flexural strength.

3.5.2 Water absorption

The cold water absorption of the specimens or tiles was tested as per Figure 3.4 using ASTM Standard method (ASTM C1167-03). The dry specimens were weighed and submerged in water for 24 hours and weighed again to determine the cold water absorption. The percentage of cold water absorption was determine by the following formula:

Absorption (C), % = $100(W_s-W_d) / W_s$

where,

W_d = Mass in air in g

W_s = Saturated mass in water after 24 h in g

Boiling water absorption can be calculated as

Boiling Absorption (B), % = $100(W_b-W_d)/W_b$

The saturated coefficient can be calculated as:

Saturation Coefficient = C/B

Figure 3.4 Water absorption test

3.5.3 Water permeability

The water permeability test of the specimens or tiles was performed using ASTM C 1167 Standard Specification for Clay Roof Tiles (ASTM C1167-03, 2003) as per Figure 3.5. The testing of the water permeability of the roofing tile was carried out by placing the roofing tile at the open bottom of a container filled with water for 24 hours.

Figure 3.5 Permeability test setup

3.6 Energy characteristics

The embodied carbon and embodied energy of the roofing tiles determine the energy characteristics of roofing tiles. Embodied energy of processing, transportation and raw materials involved in each case were obtained either from literature or based on assumptions to obtain the total embodied energy per tile as per Table 3.4. Carbon emissions were obtained for each case by the product of carbon dioxide emissions factors and the material used for different phases of lifecycle for example cradle to gate emission, production, distribution and final stage of life management. Then emissions from all the phases were added to determine the carbon emissions in each case.

Table 3.4 Assumptions in calculating the energy emissions

Steps	Assumption
Vehicle	Waste engine oil and used vegetable oil were obtained from car station and restaurant respectively at about 80 km by a car.
Production	Oven with a capacity of 15 KWh was utilized for the manufacturing of tiles. About 800 tiles were produced in an oven at one time. Tiles were sent to local vendors at about 150 km.
Final stage of life management	Waste roofing tiles were discarded in a landfills at about 30 km.

3.7 Cost Evaluation

Cost of each roofing tile was determined by raw materials and utilities charges. Cost of raw materials for each case was obtained from the local suppliers while cost of electricity was retrieved from the website of Tenaga Nasional Berhad. Moreover, the cost of raw materials for WEVO roofing tiles was calculated and compared with each case.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter shows the optimization of parameters and production of roofing tiles by utilizing waste engine-vegetable oil (WEVO). WEVO is found to be feasible for the roofing tile production after the laboratory investigation using Fourier Transform Infrared Spectroscopy (FTIR), Thermo gravimetric analysis (TGA), hardness test and Scanning Electron Microscope (SEM). The optimization of parameters such as the amount of waste engine-vegetable oil (WEVO), ratio of waste engine-vegetable oil (WEVO), compaction, curing temperature and curing duration had been performed before the optimized WEVO Roofing tile production. A few tests such as density, porosity, flexural strength, water absorption and permeability were also carried out on the standard WEVO Roofing tiles. In addition, the energy and the cost characteristics are also included in this chapter.

4.2 Laboratory investigation of WEVO

4.2.1 Fourier Transform Infrared Spectroscopy (FTIR)

The waste vegetable and engine oils were selected to be used as a binder to mix with fly ash and sand to produce roofing tile. The two types of oils were blended together with sulphuric acid, fly ash and sand in the attempt to form the roofing tile. The characterization of the waste oils had been carried out using viscometer, Fourier Transform Infrared (FTIR) spectroscopy, Thermo gravimetric analysis (TGA) and hardness test. FTIR spectroscopy shows Fourier Transform Infrared (FTIR) spectra of the base oil and other components (Van de Voort et al., 2001).The FTIR spectrum of used engine oil is composed of functional groups at bands 3385 cm^{-1} (O-H stretch), 2928 cm^{-1} and 2855 cm^{-1} (asymmetrical and symmetrical stretching vibration of (CH_2) group), 1735 cm^{-1} (ester (C=O stretch), 1708 cm^{-1} (carboxylic C=O stretch), 1463 cm^{-1}(bending vibration of the CH_2 and CH_3 aliphatic group), 1377 cm^{-1}(bending vibration of CH_2 groups), 1302 cm^{-1}(ketones (C-C stretch)), 1234 cm^{-1}(C-O stretching) and 1121 cm^{-1}(stretching vibration of the C-O ester group) as per Figure 4.1.

The FTIR spectrum of waste vegetable oil has functional groups at bands 3474 cm^{-1} (O-H stretch), 3006 cm^{-1} (=C-H(cis) stretch), 2929 cm^{-1} and 2854 cm^{-1} (asymmetrical and symmetrical stretching vibration of (CH_2) group), 2682 $cm^{-1}$and 2336 cm^{-1}(n(OH, carboxylic acid)), 1744 cm^{-1} (ester carbonyl functional group of the triglycerides), 1657 cm^{-1}(alkenes (C=C stretch (isolated)), 1464 cm^{-1}(bending vibration of the CH_2 and CH_3 aliphatic group), 1237 cm^{-1}and1163 cm^{-1} (C-O stretching), 1163 cm^{-1}(stretching vibration of the C-O ester group) and 1117 cm^{-1}(stretching vibration of the C-O ester group) as per Figure 4.1. Peak of carbonyl compound was found for both the waste vegetable oil and waste engine oil as per Figure 4.1. Therefore, using the mixture of both the oils as the binder of the roofing tile is feasible. The ratio of the mixture oils used in this study is 1 (waste engine oil): 4 (waste vegetable oil).

The FTIR spectrum of waste engine-vegetable oil (WEVO) with the ratio 1:4 has functional groups at bands 3474 cm^{-1}, 3005 cm^{-1} , 2924 cm^{-1} , 2854 cm^{-1} and 2681 cm^{-1} (O-H stretch),2681 cm^{-1} and 2854 cm^{-1}(C-H stretching), 1747 cm^{-1} (C=O stretch), 1657 cm^{-1} (C=C stretching in cis double bonds) 1400 and 1419 cm^{-1}(O-H bend), 1237 cm^{-1}(C-O stretch) and 1163 cm^{-1}(stretching vibration of the C-O ester group) and 722 cm^{-1}(rocking vibration of four successive methylene groups in a hydrocarbon chain) as per Figure 4.1. The bands in the waste engine oil, waste vegetable oil and waste engine-vegetable oil showed the presence of compounds composed of alcohol, alkanes, alkenes, aldehydes, ketones, ester and ether aromatic compound (Nurun et al., 2006). A significant peak was noticed at 1747 cm^{-1} in the waste engine-vegetable oil because of the availability of carbonyl such as ketones, ester and carboxylic acids which can react with other components. It was found that the presence of carbonyl functional group (C=O) is the main component responsible of binding the other materials to carry out the polymerization process to form roofing tile (Teoh et al., 2017). The oxidation of oil occurred with the presence of free radicals during initiation and propagation steps in a chemical reaction (Alistair, 1996).

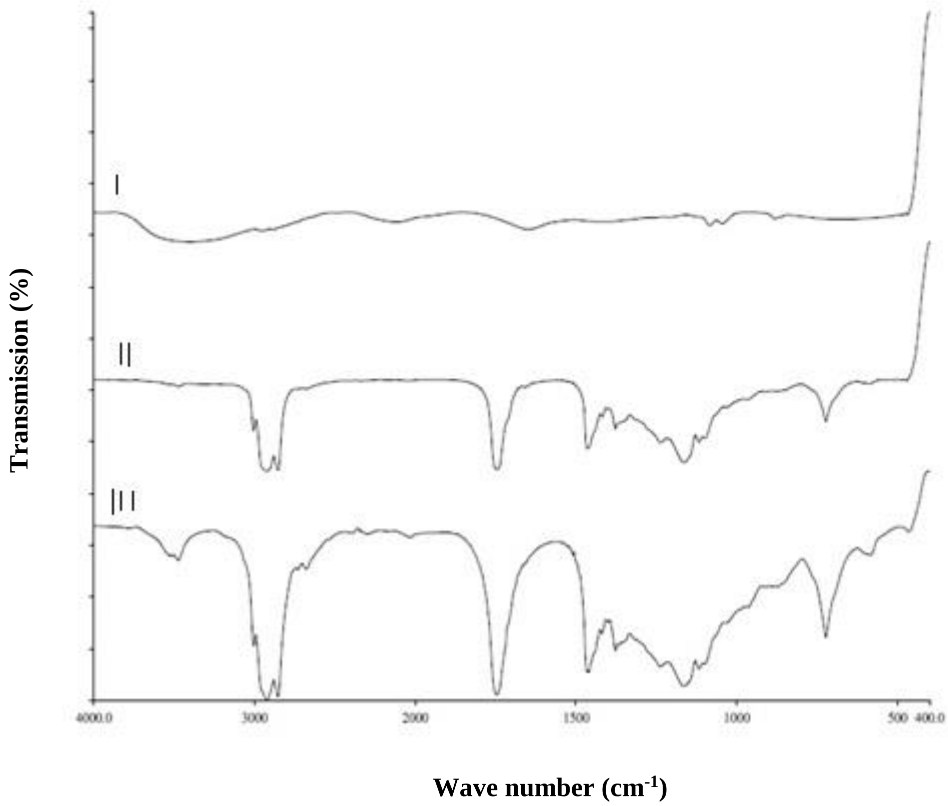


Figure 4.1 FTIR spectra of (I) waste engine oil, (II) WEVO oil and (III) waste vegetable oil in descending order.

The peaks at 3474 cm^{-1}, 3005 cm^{-1} , 2924 cm^{-1} , 2854 cm^{-1} and 2681 cm^{-1} region shows OH groups that can engaged in hydrogen bonding such as carboxylic acids or hydroperoxides (Heaton et al., 2014). Carboxylic acids do not decompose at high temperature and produce secondary oxidation products as compared to hydroperoxides (Heaton et al., 2014). A band at 1747 cm^{-1} shows the stretching vibration of the carbonyl group in the ester linkage in triacylglycerols (Heaton et al., 2014). The oxidation characteristic is found after this band such as the high concentration of carbonyl containing secondary oxidation products such as aldehydes and ketones (Heaton et al., 2014).

The oxygenated role can be obtained from the core portion of the molecule that linked to glycerol backbone or on the short-chain portion (Grosch, 1987). The band at 1657 cm^{-1} is referred to C=C stretching in cis double bonds (Heaton et al., 2014). The small peaks that are related to the double bonds are found in the a,b-unsaturated aldehydes (Heaton et al., 2014). The bands between 1400 and 1419 cm^{-1} are related to an increase in alcohols or ethers (Smith, 1999). The suspected groups for the peaks are methyl and methylene groups and the scission of hydrocarbon chains occurred and producing aldehydes and volatile molecules (Heaton et al., 2014). The band at 722 cm^{-1} indicates a peak that represents the rocking vibration of four successive methylene groups in a hydrocarbon chain (Smith, 1999). The curing part involves the breakdown and cross-linking of hydrocarbon chains (Heaton et al., 2014).

The trans-esterification reaction occurred when the oil or fat mixed with an alcohol from waste materials to produce ester and glycerol as per Figure 4.2 (Ma and Hanna, 1999). The molar ratio of 3:1 of alcohol and triglycerides had been used because the reaction is reversible. The acid catalyst was added to enhance the yield and reaction rate. Transesterification is a sequence of three consecutive reversible reactions (Ma and Hanna, 1999). The formation of diglycerides from triglycerides and alcohol, then the monoglycerides from diglycerides and alcohol and the formation of glycerol from monoglyceride and alcohol by yielding one ester molecule for each glyceride at each step is referred to as transesterification reaction which is reversible (Ma and Hanna, 1999). Oxidation can take place in the fatty acid portions of the triglyceride molecule in the waste vegetable oil as the presence of a double bond is important under normal conditions. Autooxidation of unsaturated fatty acids is a chain process occurring autocatalytically via free radical mechanisms involving the following described reactions.

The free radicals produced during the initiation stage respond with oxygen to form epoxy free radicals and hydroperoxides (Chemical reactions, 1997). Oxygen is used in a zero-order process during this period which leads to intermediates that prior in the formation of peroxides (Chemical reactions, 1997). Decomposition of secondary oxidation products leads to rancidity and toxicity. The oxygenated compounds polymerize to form viscous material as the oxidation proceeds (Chemical reactions, 1997).

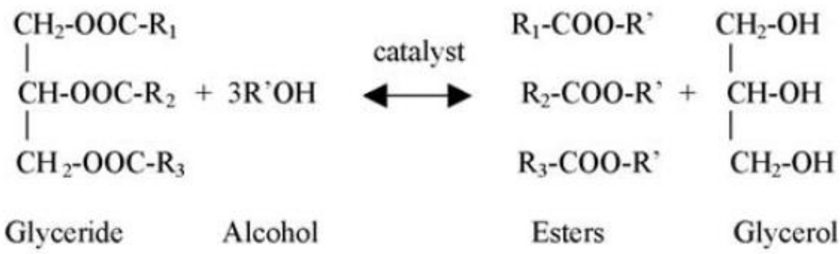


Figure 4.2 Transesterification of triglycerides with alcohol (Ma and Hanna, 1999)

4.2.2 Thermo gravimetric analysis (TGA)

TGA analysis shows that the solid oil sample has inflection point at 394.99°C as per Figure 4.3. The degradation of the solid oil sample occurred at the inflection point at 394.99°C, therefore the preferred temperature to produce the tile is below 394.99°C. The solid oil sample burned after heating and left a residue of 29.5%. The left limit was 228.81°C and the right limit was 499.16°C. The midpoint was 384.93°C. TGA is used for characterizing the thermal stability a substance by analysing the physicochemical properties of the substance (Coats and Redfern , 1963).

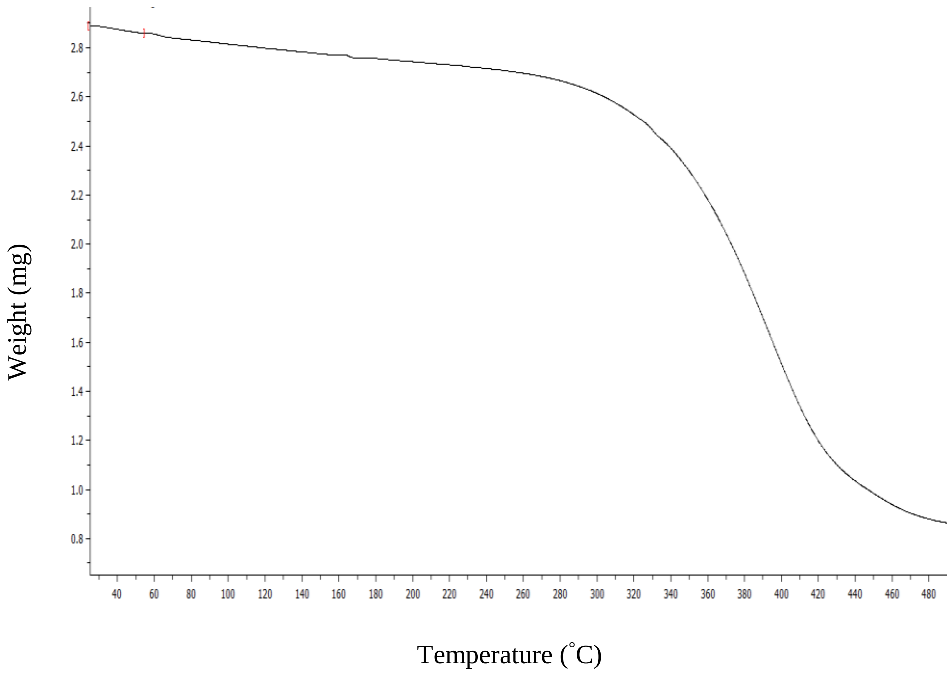


Figure 4.3 TGA analysis of waste engine-vegetable oil

4.2.3 Hardness test

According to hardness test that had been carried out, the curing durations between 15 and 24 hours at temperature 190˚C were considered suitable for the baking of each oil film as per Table 4.1. The hardness of WEVO must not below than 6B, and that of room temperature-cured WEVO must be in the range of 2H. It was noticed that the films of WEVO baked at 190˚C at curing duration of 1 hour till 8 hours were smooth and spongy. When the heating of oil lower than 8 hours showed stagnant, it could be that the functional groups such as triglycerides. A huge quantity of linkages was not cross-linked, which showed low hardness (Chaohua and Sevim, 1999). The baked-films at 190˚C at curing duration between 9 and 14 hours were smooth as a heat-cured binder. The films baked at 190˚C at curing duration between

15 and 24 hours were hardened and the functional groups such as triglycerides were strong for joining. That showed the reason of why the hardness of the baked-films at 190°C at curing duration between 15 and 24 hours was good.

The conjugated double bonds of the heat-bodied WEVO were significantly decreased in the heat pre-polymerization *via* isomerisation (Chaohua and Sevim, 1999). Therefore, the thermal-bodied WEVO showed a low capacity to form reaction with air and resulted in decreasing pencil hardness and degree of cross-linking. According to the survey on film hardness, the WEVO that is baked together with the presence of sulphuric catalysts showed heat treatment in two competitive linkages. The films baked at 190°C at lower curing duration of 1 hour till 14 hours showed isomerisation process did happen, the level of cross-linking is insufficient, and the oil film had extremely low mechanical strength (Chaohua and Sevim, 1999). The films baked at 190°C at lower curing duration of 15 hour till 24 hours showed interrelated is superior and the oil films have good mechanical strength.

Table 4.1 Pencil hardness test on WEVO at different curing durations at 190°C

Curing duration (hours)	Gouge Hardness
0	-
1	6B
2	6B
3	6B
4	6B
5	6B
6	6B
7	6B
8	6B
9	2B
10	2B
11	2B
12	2B
13	2B
14	2B
15	2H
16	2H
17	2H
18	2H
19	2H
20	2H
21	2H
22	2H
23	2H
24	2H

The preferred temperature for the baking of each oil film during pencil hardness test at 24 hours was 100°C until 200°C as per Table 4.2. The hardness of WEVO must not below than 6B, and that of room temperature-cured WEVO should fall in the range of 2H. It was noticed that the films of WEVO baked at 10°C until 40°C at curing duration of 24 hours were smooth and spongy. When the heating of oil lower than 40°C showed stagnant, it could be that the functional groups such as triglycerides. A huge quantity of correlation was not interrelated that showed low rigidity (Chaohua and Sevim, 1999). The baked-films at 50°C until 90°C at curing duration of 24 hours were smooth as a heat-cured binder. The films baked at 100°C until 200°C at curing duration of 24 hours were hardened and the functional groups such as triglycerides were unstable to interrelate. That showed the reasons of hardness of the baked-films at 100°C until 200°C at curing duration of 24 hours were good. The conjugated double bonds of the heat-bodied WEVO were significantly decreased in the heat pre-polymerization via isomerisation (Chaohua and Sevim, 1999).

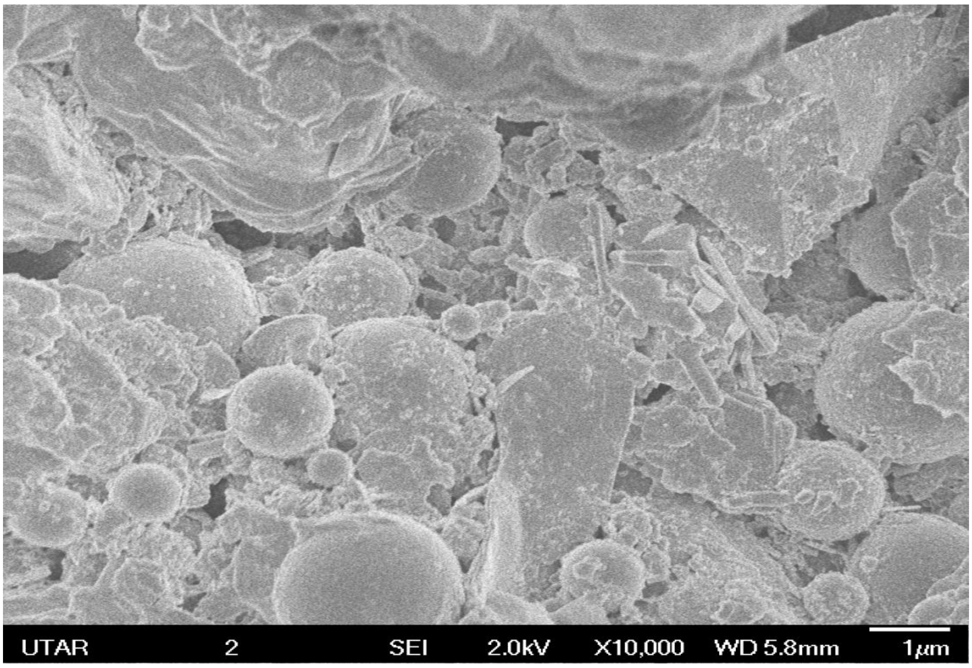
Therefore, the thermal-bodied WEVO showed a low capacity to form reaction with air and resulted in decreasing pencil hardness and degree of cross-linking. According to the survey on film hardness, the WEVO that is baked together with the presence of sulphuric catalysts showed heat treatment in two competitive linkages. The films baked at 10°C until 90°C at curing duration of 24 hours showed isomerisation process does happen, the level of interrelated is extremely insufficient, and the oil film has extremely low mechanical strength (Chaohua and Sevim, 1999). The films baked at 100°C until 200°C at curing duration of 24 hours showed interrelated is superior and the oil films have good mechanical strength which is good for the tile.

Table 4.2 Pencil hardness test on WEVO at different curing temperature at 24 hours

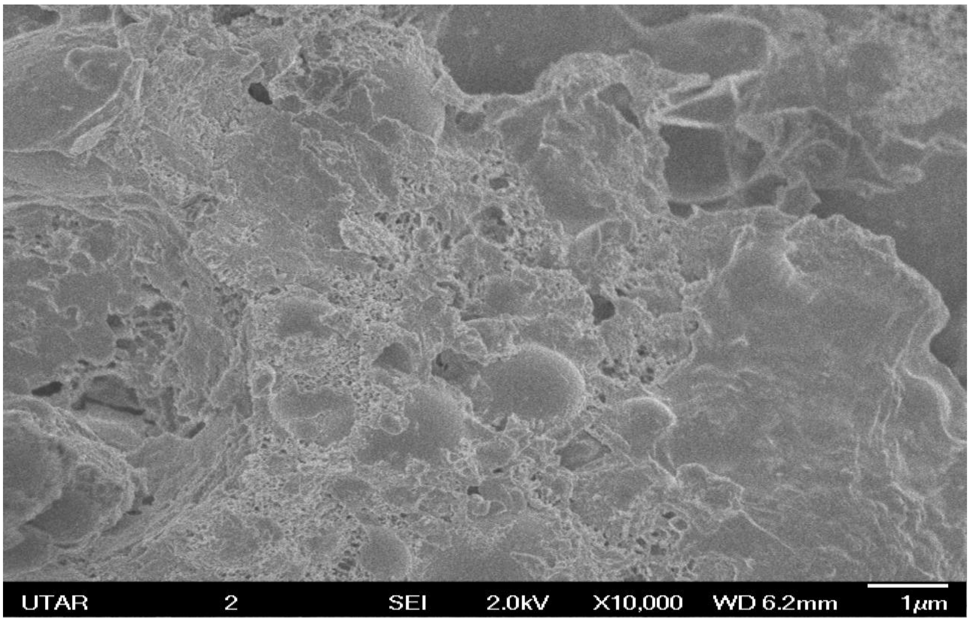
Curing temperature (°C)	Gouge Hardness
0	-
10	6B
20	6B
30	6B
40	6B
50	2B
60	2B
70	2B
80	2B
90	2B
100	2H
110	2H
120	2H
130	2H
140	2H
150	2H
160	2H
170	2H
180	2H
190	2H
200	2H

4.2.4 Scanning Electron Microscope (SEM)

The SEM micrograph of roofing tile without the presence of oil and with the presence of oil at 10000 times magnification is shown as per Figure 4.4 (a) and Figure 4.4 (b). It can be observed that SEM images show that the surface of the other ingredients was covered by polymerized oil and the polymerized oil acts as a binding material per Figure 4.4 (b) whereas many granules which are not clumped together can be found in Figure 4.4 (a). The degradation reactions such as hydrolysis, oxidation and polymerization take place when oil was heated continuously and both hydrolysis and oxidation process lead to polymerization of the oil (Sanli et al., 2011).



(a)



(b)

Figure 4.4 SEM image of interior section of the roofing tiles (a) without the presence of oil and (b) with the presence of oil at 10000 x magnification.

4.3 Optimization of parameters

4.3.1 Amount of waste engine-vegetable oil (WEVO)

The initial parameters that had been selected in the tile production were the curing temperature of 190°C, curing duration of 24 hours, 20 compaction counts by a machine and WEVO with the ratio of 1:4. The vegetable roofing tile with 35% and 50% fly ash filler were heat cured at 190°C (Noor et al., 2015).The samples of 5% of vegetable oil content by mass of aggregates were cured for 24 hours at compaction pressure of 1MPa with temperatures between 140°Cand 200°Cshowed high compressive strength compared to 120°Cto produce block (Forth and Zoorob, 2013).The specimens with 1 and 2 percent amount of WEVO in the composition were broken easily after being compacted due to the insufficient amount of WEVO to bind the materials as per Figure 4.5. The specimens with 4 percent of WEVO showed highest strength as the amount of WEVO was sufficient to bind with materials and compaction and heat curing process occurred as per Figure 4.5. As the amount of WEVO increased to 5 or 6 percent, the strength reduced significantly as per Figure 4.5. The sticky mixture as a result of the excess amount of the oil showed poor compaction process and the gaps or pores in the tile resulted in low strength.

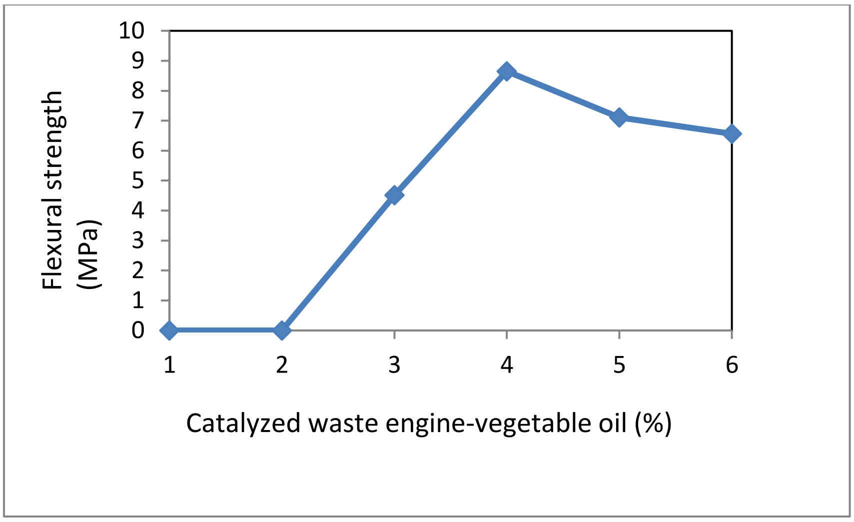


Figure 4.5 Flexural strength of specimen with different amounts of catalyzed waste engine-vegetable oil

4.3.2 Ratio of waste engine-vegetable oil (WEVO)

The WEVO with the ratio (wt %) of 0.25, 0.33, 0.5, 1, 2, 3, and 4 had been studied. The specimens were produced at the curing temperature of 190°C, curing duration of 24 hours, 20 compaction counts by a machine and amount of 4 percent of WEVO. The 0.25 ratio (wt %) of WEVO in the specimen showed the highest strength and the strength decreased gradually as the ratio of waste engine oil increased as per Figure 4.6. The high amount of waste vegetable oil in the blended oil of used engine oil and used vegetable oil such as the ratio (wt %) of 0.25 of WEVO resulted in good strength of the tile.

The ratio (wt %) of lesser than 0.25 of WEVO is not selected although it can show better strength because the waste engine oil needs to be used to a certain amount to reduce waste disposal problems to the environment. The FTIR analysis showed that waste vegetable oil has more carbonyl compounds compared to waste engine oil. The degradation reactions such as hydrolysis, oxidation and polymerization take place when vegetable oil was heated continuously and both hydrolysis and oxidation process lead to polymerization of the oil (Sanli et al., 2011).

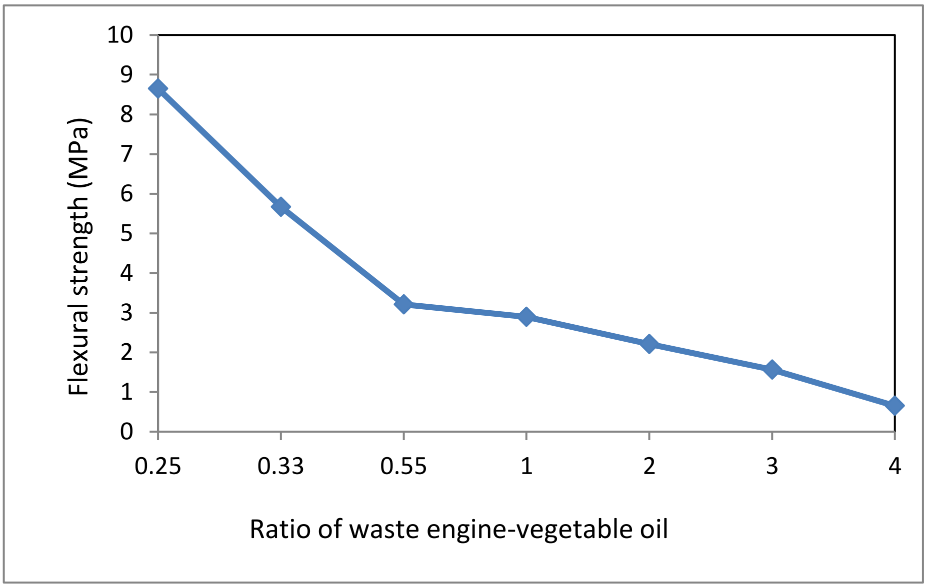


Figure 4.6 Flexural strength of specimen with different ratios of waste engine-vegetable oil

4.3.3 Compaction

The compaction rates and compaction methods such as via manual and machine compaction had been studied. The specimens were fabricated at the curing temperature of 190°C, curing duration of 24 hours, WEVO with the ratio of 1:4 and amount of 4 percent of WEVO. The specimens can be manufactured in manual compaction as it is only has a slight decrease in strength when compared to machine compaction as per Figure 4.7. The specimens that are produced in manual compaction can reduce the cost of the production compared to machine compaction. As the compaction counts increases, the flexural strength also increases. The compaction counts of 20 showed highest flexural strength in manual and machine compaction of the specimens respectively as per Figure 4.7. The compaction counts of above than 20 are not selected to produce the tiles to save the cost of the production. The highest compaction counts resulted in low thickness of the specimen as the mixture in the tile binds well when compacted and reduce the gaps or pores in the tile.

The water absorption decreases as the compaction counts increases as per Figure 4.8. The specimens fulfilled the requirement of maximum of 6 percent according to ASTM C1167-03. The porosity decreases as the compaction counts increases as per Figure 4.9. The porosity-strength relationships had been studied with Ryshkewithch, Schiller, Balshin and Hasselman model and the results showed that the compressive or tensile strength ratio decreases with the increase in porosity (Xu dong Chen et al., 2013). The specimens with compaction counts of 5 failed the water permeability test according to ASTM C1167-03 for both manual and machine compaction as per Table 4.3. The low compaction counts resulted in high thickness of the specimen and the spaces in the specimen cause the water to penetrate the tile. The porosity and water absorption of the specimens decreased as the different method of compaction was applied to the specimens as per Figure 4.10. The compaction method 1 was referred to as manual compaction whereas compaction method 2 was referred to as machine compaction. The machine compaction gives better compaction compared to manual compaction in flexural strength, water absorption and porosity.

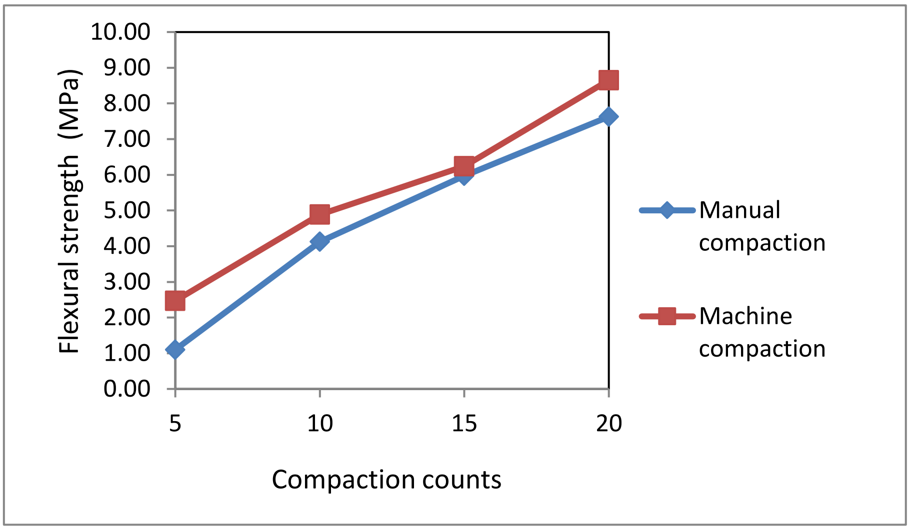


Figure 4.7 Flexural strength of specimen with different compaction counts

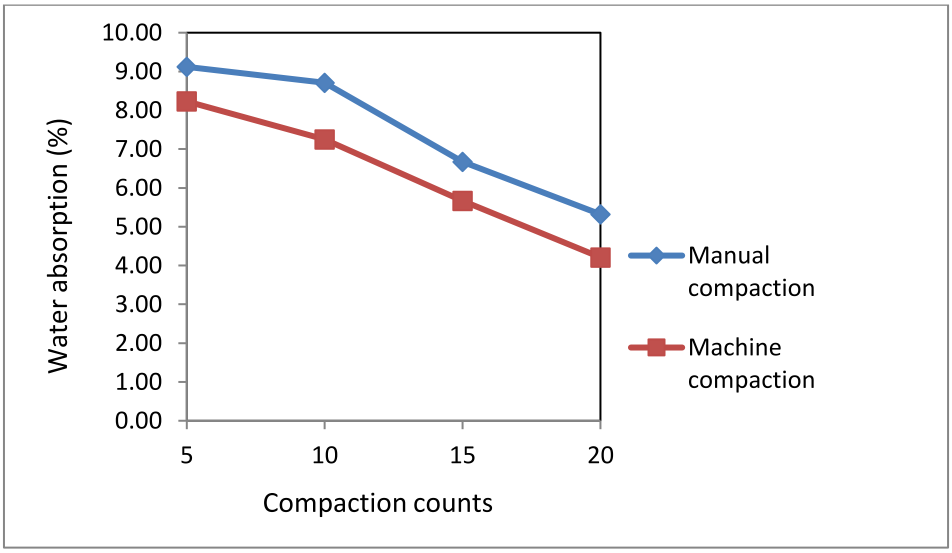


Figure 4.8 Water absorption of specimen with different compaction counts

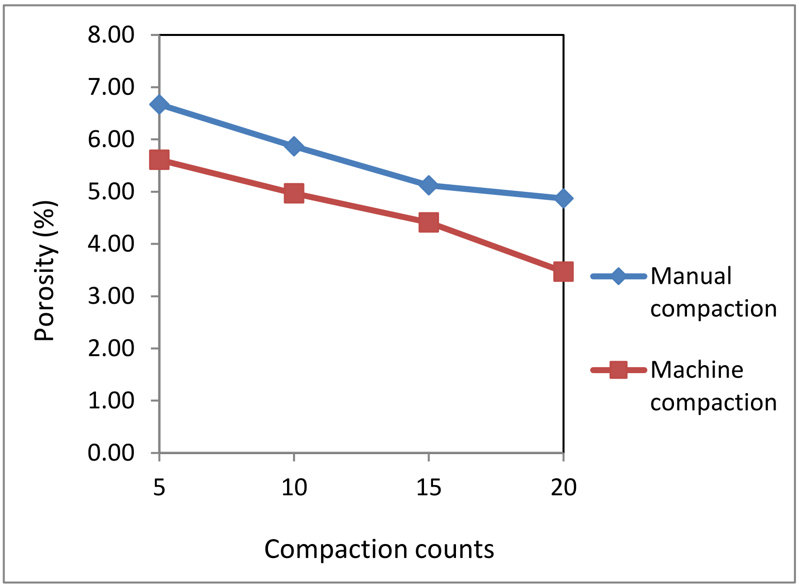


Figure 4.9 Porosity of specimen with different compaction counts

Table 4.3 Water permeability of specimen with different compaction counts

Compaction counts	Water permeability	
	Manual compaction	Machine compaction
5	Failed	Failed
10	Passed	Passed
15	Passed	Passed
20	Passed	Passed

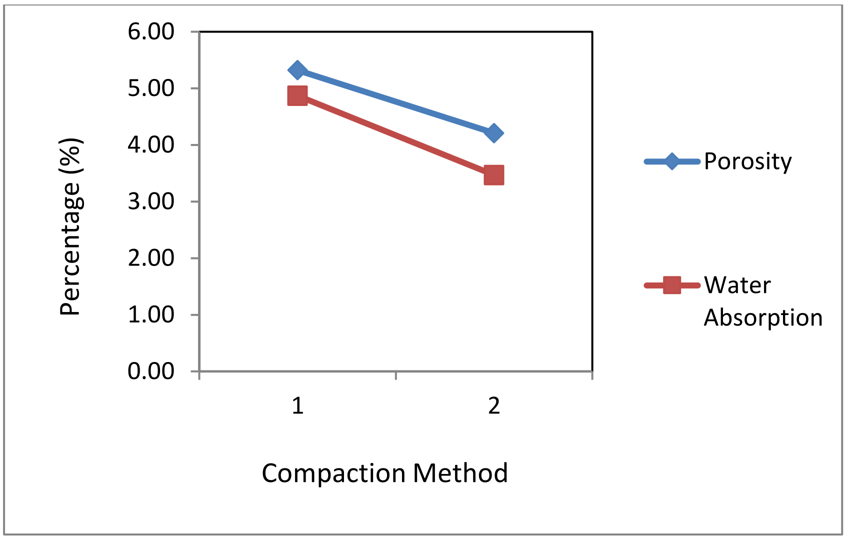


Figure 4.10 Porosity and water absorption of the specimens

4.3.4 Curing temperature

The curing temperature in the range of 100°C and 200°C had been studied (Forth and Zoorob, 2013). The parameters that have been selected in the specimen production were curing duration of 24 hours, 5-20 compaction counts by a machine, WEVO with the ratio of 1:4 and amount of 4 percent of WEVO. As the curing temperature of the specimens increased, the strength also increased, however a reduction of strength were noticed at the curing temperature of 200°C at compaction counts ranges from 5 to 20 as per Figure 4.11. The compaction counts of above than 20 are not selected to produce the tiles to save the cost of the production. The optimum curing temperature was 190°C as per Figure 4.11. The increment in heat curing temperature on roofing materials caused the spoilage of materials but the flexibility and elasticity were fine in polymeric materials (Berdahl, et al., 2008).

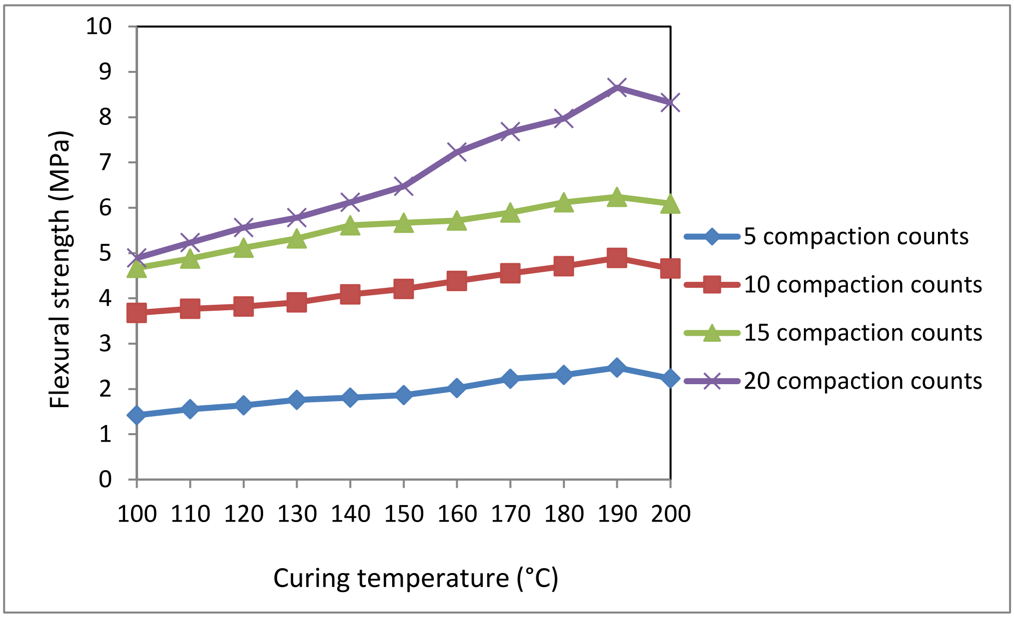


Figure 4.11 Flexural strength of specimen with different curing temperature

4.3.5 Curing duration

The curing duration in the range of 1 to 24 hours had been studied (Forth and Zoorob, 2013). The parameters that had been selected in the specimen production were curing temperature of 190°C, 5-20 compaction counts by a machine, WEVO with the ratio of 1:4 and amount of 4 percent of WEVO. The compaction counts of 20 showed the highest flexural strength of 8.65MPa at curing duration of 24 hours compared to compaction counts of 5, 10 and 15 as per Figure 4.12. The compaction counts of above than 20 are not selected to produce the tiles to save the cost of the production. The increase in curing duration resulted in high compressive strength for palm oil fuel ash geopolymer pastes (Amer et al., 2015). The specimen with the 20 compaction counts at curing duration 15 hours showed flexural strength of

6.67MPa which fulfilled the minimum standard limit of 6 MPa (CROW; Ede, 2000) as per Figure 4.12. Lower the curing duration will result in low cost of tile production.

The specimen with the 20 compaction counts at curing duration less than 5 hours showed no readings in flexural strength because the tile was unstable and need some time to harden as per Figure 4.12. The production of building blocks is by blending vegetable oil with mineral aggregate followed by a process of compaction and heat curing where the heat curing of vegetable oil in a complex auto-catalytic oxidation and polymerization as the oil component has transformed into a hard binder (Zoorob *et al.* 2006). A complex oxy-polymerisation reaction occurred when the waste vegetable oil turns into rigid binder (Humayum et al., 2017).

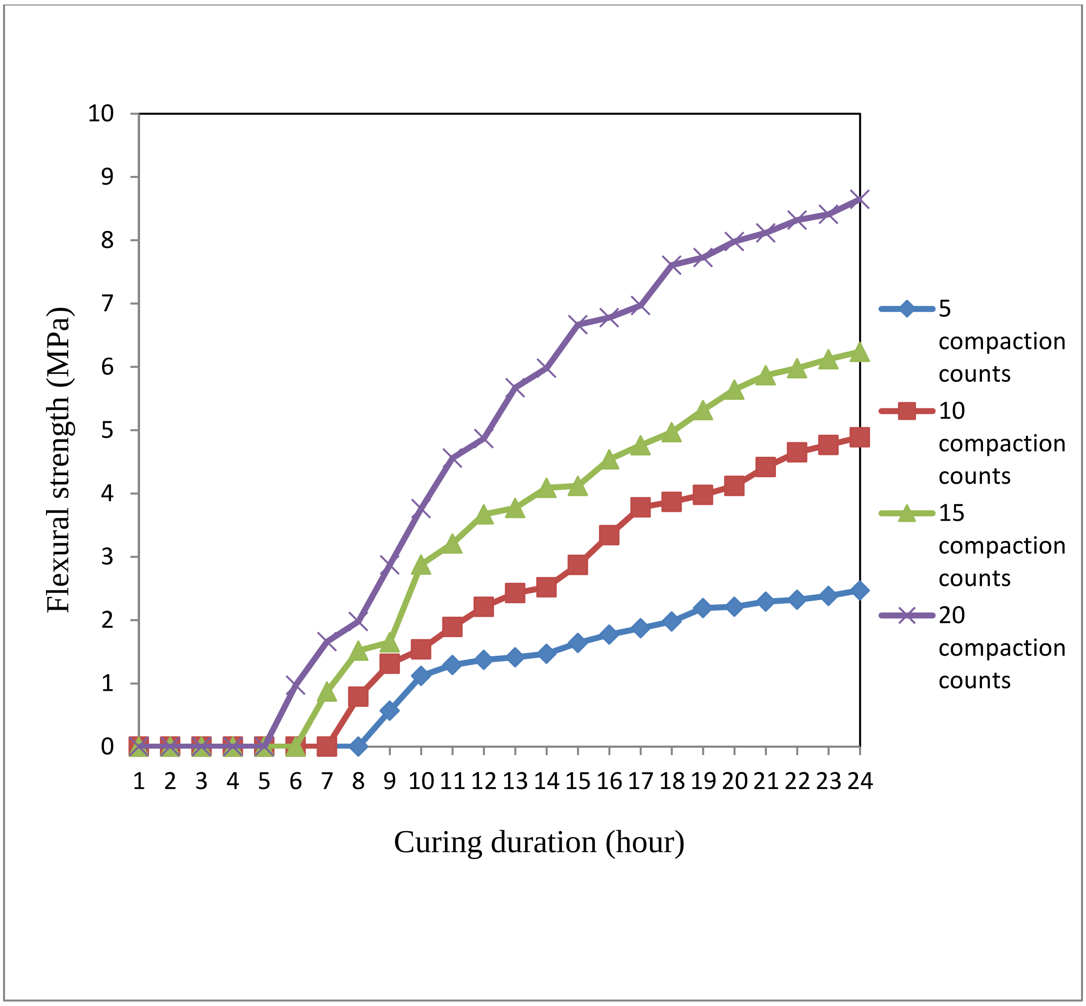


Figure 4.12 Flexural strength of specimen with different curing duration

4.4 Standard WEVO Roofing tiles

The optimized rectangular roofing tile with the dimension of 390 mm × 240 mm × 10 mm had been produced from the suitable parameters as per Figure 4.13. The parameters that had been selected in the optimized roofing tile production were i. cured at the temperature of 190°C for 15 hours, ii. having 20 compaction counts by a manual compaction, iii. using WEVO with the ratio of 1:4 and amount of 4 percent of WEVO.

Figure 4.13 WEVO Roofing tile

4.4.1 Density and porosity

The tile's density was calculated and it was in the range between 1.92 to 1.99 g/cm^3 as per Table 4.4. From Table 4.4, it shows that denser material had a lower porosity and vice versa. If the porosity was high there will be more chances that the material becomes permeable to water. The low porosity of the tile was due to good strength of roofing tile and the curing duration between 15 hours to 24 hours showed good strength of the tiles. The low curing duration resulted in low production cost of the tiles.

Table 4.4 Density and porosity of the roofing tiles

Tile No.	Mass (g)	Fly Ash (%)	Sand (%)	Catalyzed waste engine-vegetable oil (WEVO)	Density (g/cm^3)	Porosity
1	1951	15	81	4	1.92	4.9
2	1962	15	81	4	1.96	4.3
3	1957	15	81	4	1.94	4.6
4	1965	15	81	4	1.97	4.1
5	1971	15	81	4	1.99	3.7

4.4.2 Flexural strength

The optimized roofing tile has a flexural strength of 7.96MPa which fulfils the minimum standard limit of 6 MPa (CROW; Ede, 2000) as per Table 4.5. The optimized roofing tile which was subjected to accelerated weathering conditions for 900 days showed a flexural strength of 9.91 MPa which fulfils the minimum standard limit of 6 MPa (CROW; Ede, 2000) as per Table 4.6. The flexural strength of the optimized roofing tile showed an increment of 24.5% after exposing to accelerated weathering conditions for 900 days. The free radicals produced by the ultraviolet radiation from the accelerated weathering conditions might have produced more cross lingking in the matrix, thus improved the flexural strength of the tile specimen.

Table 4.5 Flexural stress of the roofing tile

Tile No.	Loading force, P (N)	Span Length, L (mm)	Width, W (mm)	Depth, d (mm)	Flexural Stress (MPa)
1	1000	130	240	10	8.13
2	900	130	240	10	7.31
3	900	130	240	10	7.31
4	1100	130	240	10	8.94
5	1000	130	240	10	8.13
Average					7.96±0.61

Table 4.6 Accelerated weathering test (900 days)

Tile No.	Loading force, P (N)	Span Length, L (mm)	Width, W (mm)	Depth, d (mm)	Flexural Stress (MPa)
1	1200	130	240	10	9.75
2	1300	130	240	10	10.56
3	1300	130	240	10	10.56
4	1100	130	240	10	8.94
5	1200	130	240	10	9.75
Average					9.91±0.61

4.4.3 Water absorption and permeability

The cold water absorption of the optimized roofing tile was 5.2% which fulfilled the requirement of maximum of 6% according to ASTM C1167-03as per Table 4.7. The saturation coefficient of the optimized roofing tile was 0.704 which fulfilled the requirements of maximum of 0.74 according to ASTM C1167-03 as per Table 4.7. The optimized roofing tile passed the water permeability test according to ASTM C1167-03. The flexural strength, durability and permeability of the optimized product influenced by the parameters used in the optimized roofing tile production such as curing temperature of 190°C, curing duration of 15 hours, 20 compaction counts by a manual compaction, WEVO with the ratio of 1:4 and amount of 4 percent of WEVO.

Table 4.7 Saturation coefficient and percentage of cold and boiling water absorbed by the roofing tiles

Tile No	1	2	3	4	5	Average
Dry mass of the tile, W_d	1955	1964	1967	1958	1963	
Saturated mass of the tile, W_s	2058.6	2060.2	2069.3	2067.6	2061.2	
Absorption of Cold Water, C (%)	5.3	4.9	5.2	5.6	5.0	5.2±0.27
Saturated mass of the tile after 5 hours in boiling water, W_B	2112.0	2099.5	2117.4	2104.1	2099.4	
Absorption of Boiling Water, B (%)	8.0	6.9	7.6	7.5	6.9	
Saturation Coefficient (C/B)	0.66	0.71	0.68	0.75	0.72	0.704±0.035

4.4.4 Energy characteristic

The embodied energy for each WEVO Roofing tile was 0.55 as per Table 4.8. Sulphuric acid, waste vegetable oil, processing, sand and fly ash showed the embodied energy of 5, 2, 0.06, 0.2 and 0 respectively (Eric et al. 2002; Reijnders and Huijbregts, 2008; Francois, 2001; Ecoinvent 3.3, 2016; Chani et al. 2003). The sum of emissions of carbon WEVO Roofing tile was 0.31kg CO_2/equivalent as per Table 4.9. WEVO Roofing tile showed the lowest total embodied energy (MJ) and total carbon emissions in different phases compared to roofing tiles produced from concrete, clay, ceramic or waste vegetable oil as per Table 4.10. Traditional high energy consuming binders were substituted by WEVO binder that can reduce the energy emissions in the environment.

Table 4.8 Embodied energy per WEVO Roofing tile

Type of material	Embodied energy* (MJ/kg)	Material required per tile (kg, L)	Total embodied energy per tile (MJ/kg)
Sulphuric acid	5[a]	0.002	0.01
WEVO	2[b]	0.078	0.156
Manufacturing	0.06[c]	-	0.06
Sand	0.20	1.620	0.324
Fly Ash	0[d]	0.3	0
Total			0.55

*a, (Eric et al., 2002); b, (Reijnders and Huijbregts, 2008); c, (Francois, 2001); d, (Chani et al., 2003)

Table 4.9 Total emissions of carbon of WEVO Roofing tile

Cradle to Gate			
Material	Quantity (kg)	Factor of emission* (kg CO_2/equiv.	Total emission
WEVO	0.078	1.00	0.078
Sulphuric Acid	0.002	0.17	0.00034
Fly Ash	0.3	0.004	0.0012
Sand	1.620	0.0048	0.007776
Production			
Operation	Electricity usage (KWh)	Factor of emission*(kg CO_2 per equiv.)	Total phase emission
Thermal Curing	0.3 (15h)	0.63	0.189
Distribution			
Material	Transport (km)	Transport emissions* (per kg, km)	Total phase emission
Extraction of materials			
WEVO	80	0.0001	0.008
Sulphuric Acid	20	0.0001	0.002
Fly Ash	35	0.0001	0.0035
Sand	20	0.0001	0.002
Product distribution			
WEVO Roofing Tile	150	0.0001	0.015
Final stage of life			
Material	Vehicle (km)	Vehicle emissions (per kg, km)	Total phase emission
WEVO Roofing Tile	30	0.00001	0.003
Total			0.31

*Factor of emission were obtained from Ecoinvent 3.3 (2016)

Table 4.10 Embodied energy and embodied carbon of roofing tiles

No	Roofing tile (390mm×240mm×10mm)	Total embodied energy (MJ/kg)	Total embodied carbon (kg CO_2 /kg)
1	Concrete	2.7[a]	0.65[b]
2	Clay	6.0[a]	0.45[b]
3	Ceramic	12.0[a]	0.74[b]
4	Catalyzed Vege	0.64[a]	0.327[a]
5	WEVO Roofing tile	0.55	0.31

[a]Humayun et al. (2017).
[b]Hammond and Jones (2011).

4.4.5 Evaluation of cost

The feasibility of the product depends on the cost of the product. The usage of water and cost of power for industrial area in Malaysia were recorded. The materials used in the production of WEVO Roofing tile was fly ash, river sand, waste vegetable oil, waste engine oil and sulphuric acid. The cost approximation for the production of WEVO Roofing tile was RM 0.86 as per Table 4.11. The cost calculated for WEVO Roofing tile was found to be less in contrast to clay roofing tile. For clay roofing tile, the cost was determined by using the clay roofing tile produced from local factory. The materials used in the production of clay roofing tile were clay, sand and glass powder. The cost approximation for the production of clay roofing tile was RM 1.39 as per Table 4.11. The rate of specific material was multiplied with the material utilized in manufacturing of each tile to obtain the rate for each tile.

Table 4.11 Economic comparison of clay and WEVO Roofing tile

Clay Roofing tile			WEVO Roofing tile		
Description	Rate (RM)	Rate per tile (RM)	Description	Rate (RM)	Rate per Tile (RM)
Clay	59322.00/metric ton	0.024	Fly ash	80/metric ton	0.024
Sand	80/metric ton	0.0001	Sand	80/metric ton	0.001
Glass powder	1384180.00/metric ton	0.55	Waste vegetable oil	800/metric ton	0.04992
			Waste engine oil	888/metric ton	0.01385
			Sulphuric acid	35.60/liter	0.001
Oven	0.38/KWh	0.76	Oven	0.38/KWh	0.76
Mixer	0.38/KWh	0.001	Mixer	0.38/KWh	0.001
Water	2.07/cubic meter	Approx 0.05			
	TOTAL	1.39		TOTAL	0.86

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The WEVO functions as a binder in the fabrication of optimized WEVO Roofing tile. WEVO Roofing tile fulfilled the standard requirements for flexural strength, water absorption and water permeability test. WEVO Roofing tile has low energy requirement compared to roofing tiles produced from concrete, clay or ceramic. The embodied energy for each WEV Roofing tile was 0.55 MJ/kg whereas the total carbon emissions in different phases of catalyzed WEV Roofing tile was 0.31kg CO_2/equivalent. Based on the experimental results the following conclusions are deduced:

1) The mixture of waste engine oil and used vegetable oil can be utilized as a binder to produce roofing tiles with appropriate compositions and manufacturing processes.

2) The oil properties were influenced by the distinct heat temperatures during the production of roofing tile. The oil

which acts a binder binds the materials at specific temperature and curing duration.

3) WEVO roofing tiles showed good flexural strength and passed water absorption and water permeability test.

5.2 Recommendation for future work

The future recommendations for the researchers are suggested as follows:

1) The use of WEVO can be performed on other construction materials such as floor tiles, ceiling tiles, building blocks and others by following the standards requirements.

2) The combination of other waste oils can be used such as petroleum oil and motor oil instead of used engine oil and used vegetable oil in the manufacturing of the tiles.

3) Different types of vegetable oils such as such as palm oil, soybean oil, rapeseed oil, sunflower oil, cottonseed oil, olive oil, palm kernel oil, peanut oil and coconut oil can be studied whether they can act as a suitable binder for the production of roofing tile.

4) Different types of engine oils such as Castrol engine oil, Shell Helix engine oil, Ferrari engine oil, Proton engine oil, Toyota engine oil, Mercedes engine oil and many more can be studied whether they can act as a suitable binder for the production of roofing tile.

5) Other type of tests such as compressive strength, abrasive, shrinkage, freeze and thaw, modulus of elasticity and many more can be carried out on the roofing tile to determine the strength and the durability of the roofing tile.

6) The addition of the cement, clay, additive, polymer such as ethyl cellulose polymer in the production of roofing tile can be studied and compared to WEVO Roofing tile.

5.3 Limitations

1) Different moulds can be used to produce the roofing tiles. The mould that has been used in the roofing tile production should have the suitable compaction machine for the production of roofing tiles. The roofing tiles are produced in manual method for compaction instead of using compaction machine for standard roofing tiles.

2) The accelerated weathering test has been carried out to determine the strength of the roofing tiles in short period of time instead of testing the roofing tiles under natural weathering conditions. Time is

limited to do outdoor weathering test therefore accelerated weathering test has been performed on the roofing tiles.

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