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THE THERMAL PERFORMANCE OF MANUFACTURED CONCRETE ROOF TILE COMPOSITE USING CLAY AND RICE STRAW FIBRES ON A CONCRETE MIXTURE

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Graphical abstract

Abstract

This paper presents a review of research on the development regarding concrete roof tile composite using clay and rice straw on concrete mixture to produce sustainable building materials in reducing indoor temperature during hot and dry weather. Architects today are less stressed about the impact and significance of roofing material to reduce indoor air temperature in the building design. Concrete roof tile is an exceptionally strong product and can endure wind and storm that would tear up other roofing types. Because of its excellent strength, concrete roof tile can withstand lifetime of your home. It is less expensive than many of the roofing tiles that it competes with a wonderful combination and its longevity. Nevertheless, concrete roof tile is non-heat insulation and also rather heavy. The combination of concrete with clay can make the concrete roof tile as a bad conductor, become heat insulation material and reduce indoor temperature level. Rice straw is the natural fiber consists of great thermal to improve indoor air quality and alleviates the issue of the weak mechanical strength of combination with concrete and clay. Besides, it can reduce the density of concrete because it has a lower density than other fibers.

Keywords: Natural fibre, pozzolanic, lightweight concrete, compressive, flexural

Abstrak

Kertas kerja ini membentangkan ulasan kajian penyelidikan mengenai perkembangan jubin bumbung konkrit komposit menggunakan tanah liat dan jerami padi dalam campuran konkrit bagi menghasilkan bahan-bahan bangunan yang mampan dalam mengurangkan suhu dalaman semasa cuaca panas dan kering. Arkitek pada hari ini kurang menekankan mengenai kesan bahan bumbung serta kepentingannya bagi mengurangkan suhu udara dalaman dalam rekabentuk bangunan. Jubin bumbung konkrit adalah produk yang sangat kuat dan boleh bertahan daripada angin dan ribut yang akan merosakkan jenis bumbung yang lain. Oleh sebab kekuatan yang sangat baik, jubin bumbung konkrit boleh menahan hayat rumah anda. Walau bagaimanapun, jubin bumbung konkrit bukan penebat haba dan juga agak berat. Gabungan konkrit dengan tanah liat boleh membuat jubin bumbung konkrit sebagai konduktor haba yang tidak baik, menjadi bahan penebat haba dan mengurangkan tahap suhu dalaman. Jerami padi adalah serat semula jadi mengandungi terma haba yang baik untuk meningkatkan kualiti udara dalaman dan mengurangkan isu kekuatan mekanikal yang lemah dalam kombinasi konkrit dan tanah liat. Selain itu juga ia dapat mengurangkan ketumpatan konkrit kerana ia mempunyai ketumpatan yang rendah berbanding serat yang lain.

Kata kunci: gentian keluli, konkrit berbusa, konkrit ringan, mampatan, lenturan

1.0 INTRODUCTION

Considering that Malaysia (located at 3.1°N and 101.7°E) is in the tropical region, it is obvious that we are dealing with great deal of problems in regards to sun and wind. It is an unpleasant climate zone that receives a huge amount of solar radiation, high temperature, high level of relative humidity, and extended periods of sunny days through the year [1].

Recently, Malaysia has gone through increased urbanization as a result of the quick growth of the urban population. Higher regional temperature increase is shown for Peninsular Malaysia compared to East Malaysia, with western Peninsular Malaysia region experiencing the highest increase. Reported by Meteorological Stations, Petaling Jaya, Malaysia has maximum temperatures 34°C in 29 January 2015. For that reason, it is actually more crucial to avoid solar radiation coming from overheating the building surfaces [2].

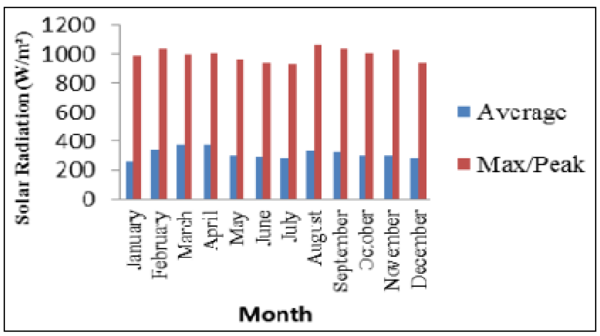

Figure 1 Monthly average and monthly peak daily total global solar radiation at the site research

Figure 1 shows information of day-to-day average for each and every month and also peak daily worldwide solar radiation for comprehensive years. The highest monthly average is in April with daily radiation of 378.76 W/m² but in August, it shows the highest daily optimal in global solar radiation of 1056.10 W/m². January possessed the lowest monthly average daily solar radiation of 254.10 W/m² [3].

As a result of phenomenon of high temperature, higher relative humidity, substantial periods of sunny days throughout the year and large of solar radiation, leading to the rising temperature and even more increased the intensity of urban heat island (UHI). Urban Heat Island phenomenon has shown that the materials used in urban development possess higher absorptive heat capacities than the soil and vegetative land cover which they replace [4]. These "hard" land surfaces take the form of roads, bridges, parking lots, walkways, patios, roofs and walls. They tend to absorb solar radiation incident on them and radiate the energy at night; raising surrounding temperature [6]. In tropical climatic locations, passive cooling is among the most challenging concerns to overcome. The efficient and the most effective option for effective cooling is by introducing air conditioning. Having said that, such equipment involves high initial and operational costs for installation, electricity and routine maintenance. Consequently, air conditioners are unexpected to be used extensively in building, particularly for low income earners. Yet additional way that can be used to lessen indoor temperature with used of sustainable building material.

Cautious analysis of thermal properties of materials is made use of in the development of urban areas is utilized as method to alleviate urban heat island. This can readjust outdoor heat environment transfer to the indoors. The principal properties governing the thermal performance of materials include reflectance and emittance (Wong, 2012). In addition, thermal conductivity is likewise part of vital properties that ought to be explored. The material with high reflectance and emittance tend to lower surface temperatures hence transfer less heat to their surrounding though convection [7].

Due to exposure to direct sun light, the roof has a huge impact on the thermal performance of the whole building [8]. About 1kw/m2 of solar radiation falling on a roof surface during clear sky condition and from 20% to 95% of this solar radiation is absorbed [9]. The roof surface absorbs and reflects solar radiation as well as it has effects on surface temperature and indoor temperature of the building.

Thermal performance of roofs can be measured through several means. These include evaluated of reflectance and emittance as the main influences on surface temperatures [10]. Thermal properties of materials include the thermal mass, convective heat capacity and thermal resistance [11]. Each one of these material properties have an effect on the surface temperature of roofs in some way.

2.0 CONCRETE ROOF TILES

The very first concrete tiles were created in Germany in the 1840s. Early manufacturing was quiet easy. Plain moulds were actually made use of while all the works were carried out manually. Automatic machines were constructed in England in the 1920s. These have been enhanced, and modern machines are very improved. With a few workers, modern factories can easily make around 10,000 tiles per person per day. Modern, high-tech equipment indicates high production volume.

Concrete roof tiles are created by combining sand, Portland cement as well as water. The sand used must have maximum grain measurement of 4 mm to fit with the concrete roofing tile density. It is essential to figure out the particle size distribution curve of the sand. This offers the excellence modulus which is equal to the area in the diagram over the distribution curve. The lower the fineness modulus, the finer the material and it is requires more water and a greater quantity of cement. The binding material is generally ordinary Portland cement. According ASTM

C187, water for concrete should be portable quality (PH 6.8 to 8.0). Tap water, fit for drinking. The water used for the mix was very clean consuming water.

Preparation and production of concrete roof tiles and also the test that were carried out on the tiles to check durability an compliance according to ASTM C1492. ASTM C1492, Travers breaking strength > 956 N, Compression strength > 17.2Mpa (7 days), Water absorption < 10%, ASTM C91 for water retention > 75% and ASTM C168-97 for thermal conductivity is lower than 0.07W/mK for thermal insulator material.

Concrete roof tile, the best commonly used as roof covering within this region. It provides certain advantages, remarkably solid product, can stand up to wind and storms, longer resilience and more affordable than other roofing material that it competes with a great combination with its resilience. Yet, the concrete roof tiles is fairly heavy and the production are not concerned with the level of thermal efficiency.

On the other hand, the manufacture of ordinary Portland cement (OPC) is highly energy intensive and environment unfriendly process required about 4 GJ of energy per tone of the finished product in addition to produce 0.8 - 1.3 ton of Co_2 per tone of cement production. Also, the contribution of Portland cement production worlwide to the greenhouse gas emission is estimated to be about 1.35 billion ton annually or about 7% of green house emission to the earth atmosphere (Malhotra, 2002).

3.0 POZZOLANIC MATERIAL

In order to produce environmentally friendly concrete, the use of fewer natural resources, less energy, and minimize carbon dioxide (CO_2) emissions [12]. The amount of CO_2 emission by cement industries can reduced cement in concrete, and by decreasing the number of building material using cement [13]. Natural pozzolans e.g. Volcanic ash, volcanic tuff, pumice and clay, and artificial from industrial plants e.g. granulated blast furnace slag, fly ash and silica fume can be used as a partial substitute for Portland cement i.e. blended cements. Each one of these materials can enhance the physical and technical performance such as boost workability, minimize permeability, increase resistance to sulphate attack, improve protection to thermal fracturing and increase supreme strength and stamina of concrete.

Pozzolana is described by ASTM C168 (1997), is siliceous or siliceous as well as aluminous material that in itself possesses little bit of or no cementing property, however it will in a finely divided form and by the present of humidity will chemically respond with alkali and alkaline earth hydroxides at regular temperatures to develop or assist in forming compounds having cementations properties.

Pozzolanic cement is a combination consisting of 20-40% natural pozzolan as well as 60-80% Portland cement. Increased amount in the natural pozzolan content of cement would lessen the permeability of the mix with the implication of a high protection to chemical attack [14] and increase in longevity.

Additionally, it was disclosed that regardless of the lower early concrete durability, the addition of natural pozzolan (up to 20-30%) might also enhance the compressive, breaking and flexural strengths of the concrete in the long term for example, over a 365 days period [15]. It is not just reinforce and secure the concrete, it has numerous other valuable features when added into the concrete mix specifically, spherical in shape, ball bearing effect, economical savings, lower volume, reduce heat of hydration, workability, improve finishing, reduce bleeding as well as reduce segregation.

Three factors that affect the activity of pozzolans. First factor is according ASTM C 618 & TS 25 minimum content of SiO_2 + Al_2O_3 + Fe_2O_3 (>70%) but a low content of MgO and SO_3 [16]. Second factor is degree of amorphous of its own structure and the last factor is brilliance of its particles where the optimum particle size is 10 μm or less, or at the very least more than 90% of the particles satisfies this prerequisite.

4.0 CLAY

Clay is one of the oldest, has a layer silicate mineral (called phyllosilicate) or other mineral which imparts plasticity and hardens upon drying or firing (Guggenheim and Martin, 1995). It could be referred to as a particle size in a soil or sediment of a diameter < 0.002 mm or 2 microns. Clay made up of silica (SiO2), alumina (Al2O3) and water (H2O) plus significant concentrations of oxides of iron, alkali and alkaline earth. Figure 2 shows the pore size arrangement in clay.

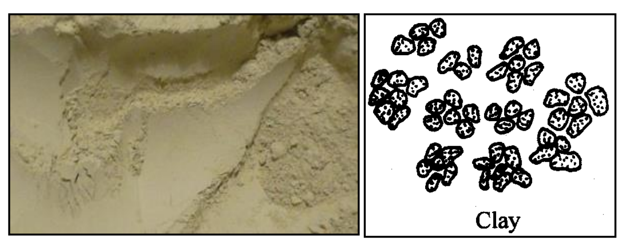

Figure 2 Pore size arrangement in clay

Chemical properties of clay shows the clay is contains high amounts of silica and alumina but includes a crystallic structure. So that, it does not possess pozzolanic activity and non-amorphous substance. Nevertheless, by heat treatment, including calcining between 700 ^{0}C to 90 ^{0}C, this crystallic structure is ruined and a quasi-amorphous structure is acquired.

Clay has a physical and mechanical properties for example plasticity, shrinkage under heating and under air-drying, fineness of grain, colour after firing, solidity, lightweight, cohesion, and capacity of the surface to take decoration. Clay is the healthiest and also the most effective substance that one can use in order to construct a sustainable building material in development.

Clay is "good thermal mass", it is very good at retaining temperatures at a steady level. Clay holds heat or cold, releasing it over a period of time like stone. Clay is a living, breathing building material which in fact enhances the air around it, absorbing and releasing humidity comparatively fast. This leads to a naturally controlled level of humidity and with it a healthier room environment is attained. Hence, designing and build with clay will contribute significantly to cut energy used.

5.0 RICE SRAW

Lignocellulosic agricultural byproducts certainly are a massive and low-cost source for cellulose fibers. Agro-based bio fibers possess the composition, properties and structure which make them ideal for multiple uses namely composite, textile, pulp and paper production. Moreover, bio fibers can also be used to create fuel, chemicals, enzymes and food.

Rice straw is one of the most considerable agricultural trashes and one of the natural fiber. The National Food Security aims to increase the National Self Sufficiency Level (SSL) of domestic rice production. Malaysia needs to produce around 2.5 million metric tonnes of paddy annually [17]. Meaning that around the same volume of rice straw was produced in that year [18]. On the other hand, the increase in productivity and size of paddy areas, among other things, has resulted in a enormous surplus of rice straw where the most cost-effective manner of getting rid of the residue is seen as burning the biomass in the paddy field which causes severe air pollution.

Rice straw is categorized as non-wood fibers, it is most useful as fibre for construction supplies, papers and also as animal feeds. Among the various agricultural straws, rice straw could be very interesting material as filler in biodegradable polymer composites, due to its good thermal stability, competitive specific mechanical properties, and availability, low cost and lightweight compared to other agricultural waste [19]. The rice straw can effortlessly be grinded into chips or particles, which are very similar to wood particles or fibers. It is also are obtainable on a international basis and considered for renewable materials. They can be obtained at low cost and low levels energy using local manpower and technology [20].

The rice straw is primarily contains of carbohydrate components such as hemicelluloses, cellulose, and lignin. Table 1 shows the percentage composition of rice straw. The chemical constituents of natural fiber like rice straw have specialized functions in the cell wall: cellulose forms strong and stiff crystalline regions, cellulose and hemicellulose form semi-crystalline regions which provide necessary flexibility while the amorphous regions of lignin give thougness and cohesion.

Table 1 Percentage compositions of rice straw

Components Composition (%)	Composition (%)
Cellulose	37
Hemicellulose	24
Lignin	14
Others	25

The mechanical properties of natural fibers depend on its cellulose type because each type of cellulose has a unique cell geometry which determines the chemical compositions. Hemicellulose chains to cellulose by hydrogen bonding and acts as cross linking molecules between the cellulose microbrils forming the cellulose-hemicellulose network, which can be considered to be the primary structural component of the fiber cell. Lignin is the compound that offers hardness to the fibers. Rice straw fibers could not reach great heights or rigidity without lignin.

The rice straw resistance to microbial decomposition and enables this material appropriate as filler in building composite materials. Alternatively, high content of silica (up to 20%) signifies an additional potential benefit regarding the flame-retardant when utilized in building industry. From this perspective, rice straw has been examined as possible filler in various thermoplastic matrices.

The rice straw skin features a waxy structure which can result in poor cohesiveness with cement. It gives tensile strength, as rebar does in concrete. Rice straw is unique relative to additional cereal straws in being low in lignin and high in silica. Rice straw fibers strength of 3.5 g/denier (450 MPa), elongation of 2.2%, and modulus of 200 g/denier (26 GPa), similar to linen fibers (Reddy, 2006).

The untreated rice straw has the greates tensile strength than treated by water and NaOH [21]. NaOH treatment decreases the strength than water treatment due to the elimination of amorphous compounds such as lignin and hemicellulose [22]. Concrete filler rice straw clearly reduce the maximum hydration temperature attained (T) and increase the time of achieves the maximum temperature (t) as compared with normal concrete.

Rice straw cementitious composite has a potential to be used in the production of a new lighter building material like brick due to its low density than other fiber [23]. In the same study, water absorption and thickness swelling of straw cementitious composites were in the same range of wood cement composite material.

6.0 CONCLUSION

Clay is natural pozzolan can be used as an admixture to produce concrete roof tiles composite to enhance the physical, mechanical as well as thermal performance as roof covering application. Clay as high thermal mass enables the building respond to temperature fluctuations through the entire day, which can aid in improving building comfort and reduce peak energy demands. Thermal mass is the ability of a material to store heat. Throughout peak temperature hours, a substance with high thermal mass will absorb heat, instead of transfer it to the living space.

Utilizing rice straw for high-value fibrous applications will help adding value to the rice harvests, provide a sustainable resource for fibers, benefit the environment and also can increase farmer's revenue. Concrete roof tile composite using clay and rice straw can improve the insulating qualities of the roof and raise the comfort level in the building. Aside from that, these clay and rice straw usage in concrete roof tile mixture can create roofing tiles as an substitute in providing cost-effective concrete roof tiles in low cost housing development.

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