Global Warming Control Using Thermal Insulator Paving Bricks

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Abstract- In developed urban areas, paved surfaces such as footpaths, car parks and other paved grounds, account for large open surface area which is susceptible to solar radiation from the sky. Dark and gray materials such as asphalt and concrete paving bricks are generally used to pave these surfaces and thus absorb the incoming solar radiation. The absorbed solar radiation is converted into heat, causing the surface temperature to become higher than the ambient air temperature; the infrared radiation is then re-emitted. As the surface becomes warmer, the local ambient air temperature also increases. This effect of air and surface temperatures to be warmer than their surrounding areas creates a heat island effect. This study has explored the possibility of employing coconut and grass fibers in paving bricks to create insulation in the paving materials. To this effect paving bricks were manufactured by using local traditional methods. To start with, the engineering properties of the insulated paving bricks were determined and it was established that they satisfied the quality requirements as stipulated in ASTM C 902 "Specification for Pedestrian and Light Traffic Paving Brick" [2], thus making them suitable for use. The heat flow test results show that the paving bricks which are composed of grass layers and coconut fibers have demonstrated lower thermal conductivity as they took longer time to absorb heat and shorter time to lose it in comparison to normal solid paving bricks.

Keywords- bricks, grasses, coir, temperature, paving

I. INTRODUCTION

Heat island effect is a big problem especially in urban areas whereby higher temperatures are experienced than in rural areas due to congestion of buildings. The main causes of the urban heat island effect are the construction activities on the land surfaces using materials that effectively store short-wave radiation. The principal reason for the nighttime warming is the short-wave radiation heat retained in the concrete, asphalt, and paving blocks after it was absorbed during the day; it is then slowly released during the night as long-wave radiation, thus slowing the cooling process. Roads are usually paved with black asphalt while pedestrian walkways and parking lots are paved with concrete paving bricks. These surface materials do absorb most of the sunlight heat to which they are exposed. The solar radiation is then converted into thermal energy, and when these pavements heat up, they heat the ambient air. The reasons for heat island effect include the following;

i. Displacement of vegetation and trees because of human activities and artificial land cover which minimize the natural cooling effects of shading and evaporation of water from soil and leaves (evapotranspiration) and removal of carbon dioxide in the air.
ii. Narrow streets and tall buildings provide multiple surfaces for the reflection and absorption of sunlight, increasing the efficiency with which urban areas are heated up. Another effect is blocking of wind, which also inhibits cooling by convection and pollution from dissipating.
iii. Waste heat from vehicles, factories and air-conditioners can increase heat island effect because many forms of pollution change the radiation properties of the atmosphere.

Mitigating the heat island effect requires modifying ground surfaces covered with concrete and asphalt, which demands the development of new paving techniques, recreation parks and other green spaces as well as planting of street trees. In this study**, thermal insulator paving bricks** composed of cement; sand and water complemented by either coconut fibers or grass have been studied and compared with the solid common paving bricks made from a mix of cement, sand and water only. The comparison was focused on strength, water absorption, heat absorption and the cooling rate.

II. PROBLEM STATEMENT

The effect of heat energy in city streets is caused by several reasons; one of them is type of pavement materials used, which in the absence of vegetation and trees the cooling effect of the surface is reduced hence resulting in the increase of temperature in the city. This calls for the need to have pavements which have thermal insulator properties thereby reducing heat energy effect in the environment. The effect of heat island results in several problems such as;

i. The increase of air pollution level, because higher temperature accelerates power plant emission of harmful pollutants;
ii. The increase in energy demand to cool buildings and homes in the vicinity of heat islands.
iii. Heat islands can amplify extreme hot weather events, which can cause heat stroke and may lead to physiological disruption, organ damage, and even death – especially in vulnerable populations such as the elderly.
iv. As heat island effect raises the temperature of cities, it also increases the concentration of ozone in the air, which is a greenhouse gas.

All the above problems call for a scientific solution in order to reduce the heat island effect.

III. OBJECTIVES

The main objective of this study was to attempt to reduce heat absorption and to increase heat loss in paved grounds/streets by using insulated paving bricks and at the same time reduce environmental pollution by using waste materials i.e. coconut fibers and grass. The specific objectives were twofold, namely;

- To check the suitability of thermal insulator paving bricks in terms of compressive strength, durability (abrasion index and water absorption) and compare with the normal solid paving bricks;
- To investigate the heat energy reduction in city streets by using thermal insulator paving blocks;

IV. REVIEW ON URBAN HEAT ISLANDS AND PAVING BRICKS

A. Urban Heat Islands

An urban heat island, or UHI, is a metropolitan area that's a lot warmer than the area surrounding it. Urban heat islands are created in densely populated and densely constructed places that have lots of activities which burdens not only the waste disposal but also control of heat generation between buildings in the UHI. Nighttime temperatures in UHIs remain high on lower levels of the buildings because the emission of heat from the ground is trapped by the parking lots. Scientists are studying to establish to which extent urban heat islands contribute to global warming. According to Sweeney et al [1], some of the mitigation measures already being practiced to control the heat island effect in urban areas include the use of green roofs and use of lighter coloured materials on building constructions

Paving Bricks

Paving bricks are those types of bricks that are locally manufactured, as displayed in Figure 1, to be used for paving the ground surface. They are manufactured to withstand both hot and cold temperatures, snow, rain, pedestrian traffic as well give access to light vehicles. The paving bricks are manufactured in conformity to the ASTM C 902 code [**2**].

Figure 1: Paving bricks

B. ASTM C902 PAVER SPECIFICATIONS

The American Society for Testing Materials gives standards for building materials including pavement. ASTM C902 [**2**] gives specifications for different classes of bricks in terms of compressive strength, water absorption and abrasion index depending on the intended use. The case study at hand was guided by ASTM C902 class MX specification for bricks to be used as pavers for low weight vehicles, bikes, and pedestrians.

Compressive Strength of class MX bricks must have a minimum compressive strength of 2,000 pounds per square inch (**13.79 N/mm^2**) while cold **water absorption** requirement for class MX must not exceed 14% of the water it is exposed to and, accordingly, the **abrasion limit** provided for is 0.5

V. PRODUCTION OF PAVING BRICKS

A. The case study

The materials for the case study involved the commonly used Heidelberg Portland cement mixed with sand and water to produce class MX pavers. For the case at hand coconut fibers or grass were added in replacement of sand percentagewise targeting to create thermal insulation properties in the paving bricks.

B. Manufacturing of paving bricks

Fig. 2. Mixing of materials

Fig. 3. Compaction by tamping

Most of paving bricks used in Dar es Salaam for pedestrian use and light vehicle access are manufactured locally using simple tools as portrayed in Figures 2 and 3.

For the purpose of this study a total of 65 paving bricks with the standard size of 200 x 100 x 70 mm have been produced. Three sample types of paving bricks were prepared as follows:

First sample: These were solid paving bricks which are traditionally manufactured for paving purposes by most vendors in Dar es Salaam. Sand and cement were mixed manually according to the specified ratio of 1:6 and mixed with water to obtain the required workability. Molding of the bricks was done using the steel mould to ensure easy release of the brick from the mould without any deformation or breakage of the brick. The mixture was pressed into mould and compacted by repeated ramming with prismatic wooden block and shovel (see Figures 2 and 3). The brick was then released from the mould and air dried for one day; thereafter the sample was cured in water for 28 days. This process was repeated for each

Figure 4: Mafinga Grasses

individual sample brick.

Second sample: The mix ratio of materials remained the same, but in this case, two

Fig. 5. Coir (coconut fibers)

Fig. 6. Fibrous husks

layers of grasses were introduced in the bricks to instill the insulation property. The grasses were collected from Mafinga, where they are commonly used as roofing materials. The grasses were cut in 14 - 16 cm pieces long as portrayed in Figure 4 to allow for sufficient end cover of at least 10 mm.

The two layers of grasses were inserted such as to allow for 2cm top and bottom cover, and approximately 1cm between the two grass layers. The compaction and curing process of the bricks remained the same as for solid paving bricks.

Third samples: The mix ratio of materials remained the same but added with coconut fibers as coir [**4, 5**] by percent weight in three different quantities, namely 0.5%, 1% and 1.5%. The fibrous husks were obtained from Msasani area in Dar es Salaam. The husks were air dried for two weeks then canned by a wooden stick to produce coir which was then resized into small pieces of 3 cm ready for use; see Figures 5 and 6. The mix was then filled in the mould, and compaction and curing process of the bricks remained the same as for solid paving bricks.

VI. TESTING THE CASE STUDY PAVING BRICKS

The paving brick samples were tested in order to establish their engineering properties, and to assess the extent to which they conform to the minimum required standards in terms of compressive strength, water absorption, abrasion resistance as well as the induced **heat insulation** property.

The adopted key notations in the test results and in the graphs are as detailed below:

C1.5 means the sample paving bricks contain 1.5% of coir

C1.0 means the sample paving bricks contain 1.0% of coir

C0.5 means the sample paving bricks contain 0.5% of coir

G means sample of paving bricks which compose of two layers of grass

N means normal solid paving brick sample

A. Dry Compressive Strength Test

The aim of this test was be to determine the compressive strength of paving bricks against vertical loading. The test setup was as depicted in Figure 2.

Fig. 2. Compressive test (brick under test)

The graph in Figure 3 shows the test results on compressive strength for the twenty five bricks.

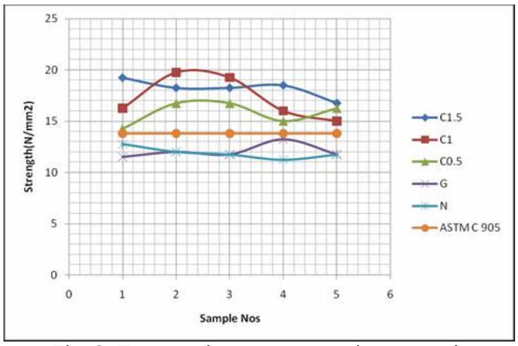

Fig. 3. Test results on compressive strength

B. Water Absorption Test

The test was carried out in order to assess the water absorption of the paving bricks. The test was done according to the following procedure:

i. Twelve bricks were weighed and completely soaked in water tank at room temperature for 24hrs.
ii. The bricks were then removed from the water and allowed to drain for one minute then surfaced dried.
iii. The saturated and surface dry bricks were immediately weighed.

The obtained test results are shown in Figure 4 and Table 1.

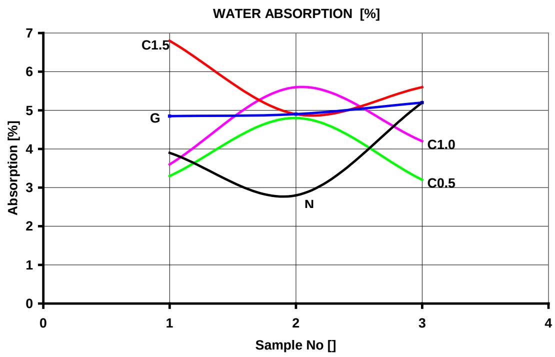

Fig. 4. Test results on water absorption

The water absorption was found to fall within the specified maximum value of 14%.

C. Abrasion Index Test

Abrasion index is a measure of the resistance of paving bricks to the wearing action due to traffic and is computed by dividing the water absorption by the compressive strength (units of psi) and then multiplying by 100.

TABLE 1: ABRASION INDEX RESULTS

Brick samples	Average compressive strength		Average water absorption %	Abrasion Index
	N/m^2	psi		
C1.5	18.1	2625	5.8	0.220
C1	17.2	2495	4.4	0.176
C0.5	15.6	2233	3.8	0.170
G	12.4	1798	3.9	0.217
N	12.0	1740	5.1	0.293

The Abrasion Index was found to be ranging from 0.17 to 0.293 being within the allowable limit of 0.50.

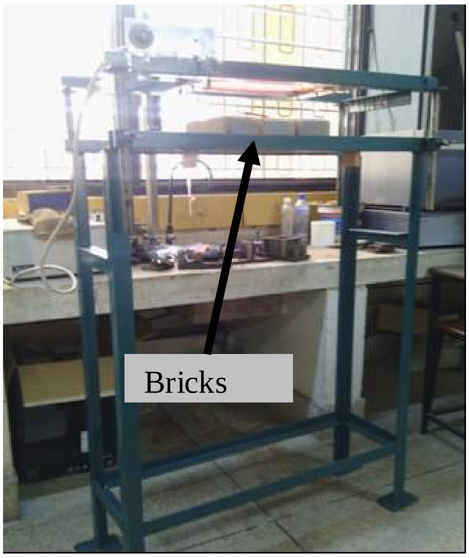

Fig. 5. Heat flow test set up

HEAT FLOW TEST SET UP

A. Introduction of the machine

The heat flow machine was designed at the College of Engineering and Technology, University of Dar es Salaam by Dr J. Makunza. It is consisted of a steel frame, thermostat and heating chamber. The frame costs USD 350 while the cost for the heating chamber and thermostat amounts to USD 170.

B. How it works

The machine uses electricity as a source of energy. The maximum heat it can emit is 300°C. The heating chamber has two lamps in-built for heat energy transfer from a body with a higher temperature to the one with a lower temperature through electromagnetic radiation. A thermostat is a systems' control component with a sensor to maintain the desired set temperature. The thermostat operates by switching on and off the heating/cooling devices to maintain the correct temperature [**3**]. Its frame can be adjusted to fit the size of the specimen.

The heat flow test set up, which measures the rate of heat flow in the paving bricks, is shown in Figure 5 the function of which is elaborated as follows:

The brick samples were marked accordingly whereby the normal solid paving bricks were used as reference.

i. The brick samples were adequately spaced from one another to allow for the flow of air and avoid the transmission of heat between the samples.
ii. The readings were taken at the bottom surfaces of the bricks at an interval of 30 minutes for two hours.

After two hours the samples were removed from the machine and left to cool down.

VII. HEAT FLOW TEST RESULTS

A. The heating up of sample bricks

The test sample bricks were subjected to controlled heat increase up to 84°C maximum. The temperature was measured by using infrared thermometer placed at the bottom and top surfaces of brick samples and the recorded results are presented in Figures 6 –

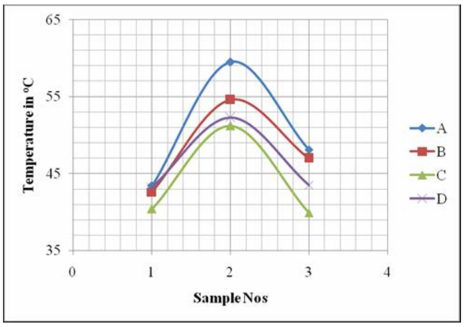

Figure 6: Temperatures recorded after 30 minutes

9. Following are the descriptions of key notations to the samples in the graphs:

A1 and A3 represent samples which contain 1.5% of coir

B1 and B3 represent samples which contain 0.5% of coir

C1 and C3 represent samples which contain grass layer

D1 and D3 represent samples which contain 1.0% 0f coir

A2, B2, C2 and D2 represent solid bricks which were used as reference bricks

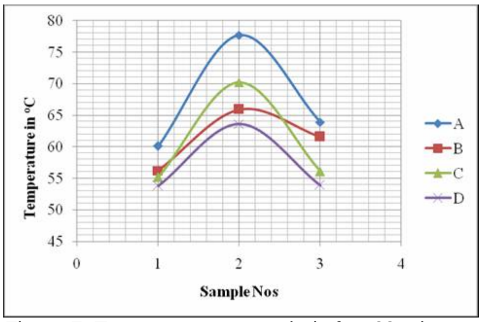

Figure 7: Temperatures recorded after 60 minutes

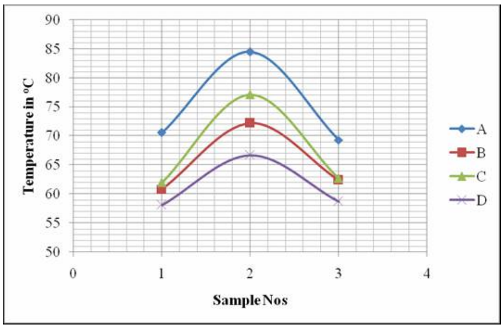

Figure 8: Temperatures recorded after 90 minutes

B. The cooling of sample bricks

The test sample bricks were removed from the machine and left to cool for two hours. The temperature during cooling process was recorded at interval of 30 minutes to study their behavior of loosing heat. The results are shown in the Figures 10-14.

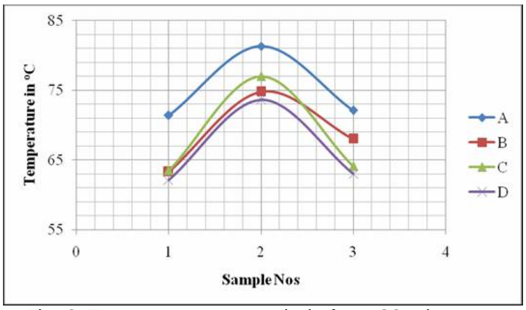

Fig. 9. Temperatures recorded after 120 minutes

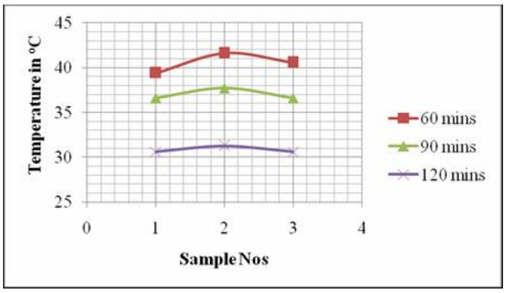

Figure 10: Cooling temperature recorded for sample bricks C1.5 and N

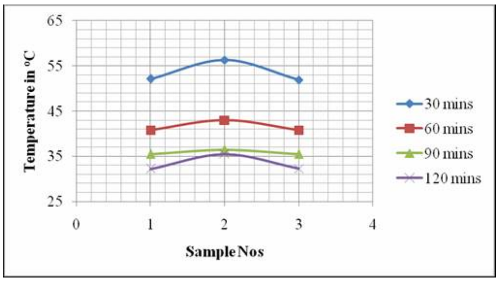

Figure 11: Cooling temperature recorded for sample bricks C1.0 and N

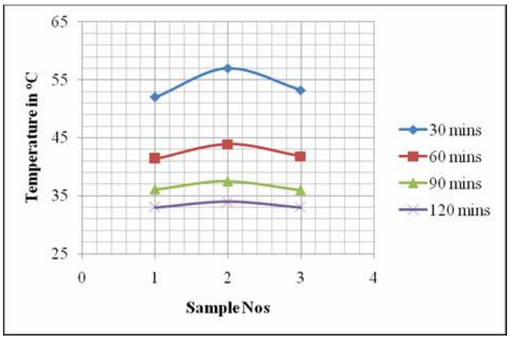

Figure 13: Cooling temperature recorded for sample bricks C0.5 and N

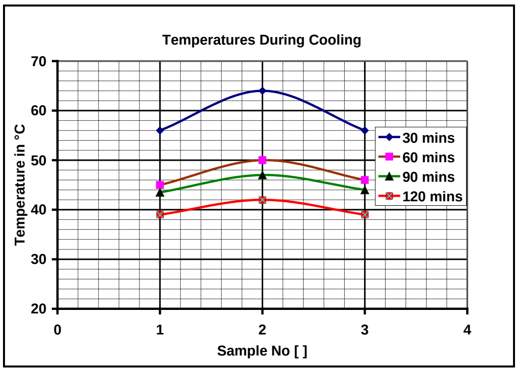

Figure 14: Cooling temperature recorded for sample bricks G and N

VIII.RETESTING THE SAMPLE BRICK PROPERTIES

After the cooling effect, the sample bricks were retested to ascertain the retention level of the engineering properties in terms of compressive strength, water absorption and abrasion index, the results of which are reflected in Figures 15 and 16 as well as Table 2.

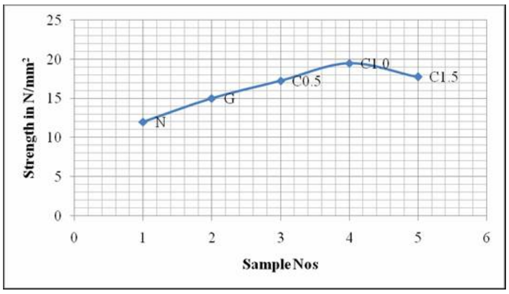

Fig. 16. Water absorption

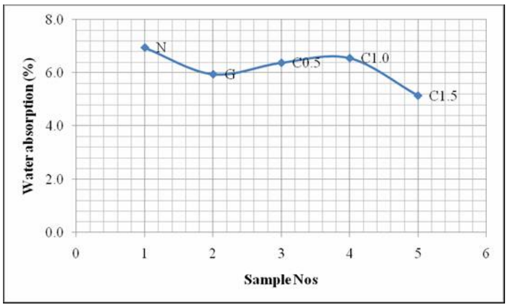

Fig. 15. Compressive strength

ASTM C 902 states that the minimum compressive strength required is 13.8 N/mm^2 ASTM C 902 states the maximum average 24 hr cold water absorption required is 14%.

TABLE II. ABRASION INDEX

Brick samples	Compressive strength (N/mm^2)	Compressive strength (psi)	Absorption (%)	Abrasion index
C1.5	18.2	2640	5.8	0.22
C1	19.5	2828	4.4	0.16
C0.5	17.0	2465	3.8	0.15
G	15.0	2175	3.9	0.18
N	12.1	1610	5.1	0.32

ASTM C 902 states the maximum abrasion index accepted is 0.50.

IX. DISCUSSION OF TEST RESULTS

A. Compressive strength test

The compressive strength of the brick pavers with insulation material has remained within the required strength value as per ASTM C 902. In addition the coir fiber flexibility provides a structural mesh behavior in the paving bricks thus enhancing the compressive strength of up to 18.2 N/mm^2.

B. Water absorption test

The average 24 hrs cold water absorption (porosity) of the paving bricks has maintained the levels between 3.8 and 5.1%, which is within the acceptable limit of 14% according to ASTM C 902.

C. Abrasion resistance

From the compressive strength test and water absorption test results, the abrasion resistance index was calculated and found to remain in the range between 0.15 and 0.31, which conforms to the maximum value of 0.50 as per specified in the ASTM C902.

D. Heat flow test

The aim of the test was to study the heat flow in paving bricks in line with the objective of the project targeting to reduce amount of heat in the pavements. The sample bricks which contain grass and coconut fibers have demonstrated the low rate of heat flow compared to the normal solid paving bricks, which indicates that introducing coir fibers and grass into bricks manufacturing creates barrier to heat conductivity.

During the cooling process the paving bricks which contained coir and layers of grass were losing heat faster compared to the solid paving bricks; therefore the materials can be used to produce thermal insulated paving bricks.

X. CONCLUSIONS AND RECOMMENDATIONS

- Basing on the results obtained in this study, it has been established that paving bricks consisting of coir fibers 1.5%, 1.0%, 0.5% or two grass layers with a mix ratio of 1:6 for cement: sand have compressive strengths, water absorption and abrasion index which comply to ASTM C 902 specifications
- The technology used to manufacture the insulated paving bricks is more environmentally friendly because it uses waste materials;
- The introduction of coir and grass layers induces insulation properties in the bricks thereby reducing thermal conductivity hence reducing the urban heat island effect;
- Since results of this study have demonstrated that the insulated paving bricks meet standard required by ASTM C902 and are at the same time effective in reducing the heat island effect they are strongly recommended for use to pave

pedestrian walkways and parking lots for light vehicles.

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