Design and Testing out of an Insulating Floor Element, Composed of Recycled Rubber and Inert Demolition Waste

Vincent Buhagiar, PhD
University of Malta
vincent.buhagiar@um.edu.mt

James Bonnici, B.E&A

Simon P. Borg, PhD
University of Malta

ABSTRACT

Even if initially dominated by cost concerns, energy-awareness is today maturing towards a vision aimed at curtailing energy consumption and reducing carbon emissions.

In consideration of today's large amount of tyres being used and disposed of, the purpose of this research was to investigate options for utilising recycled rubber as a building material (in combination with inert demolition waste), namely as insulation in flooring elements such as tiles, such a mix could replace new underlay insulating materials typically having a higher embodied energy content. This paper evaluates the potential of recycling used tyres in specially fabricated floor tiles for different design mixes and evaluates the success/failure of such a building element as a floor finish.

The study also looks into the best combination of materials to form a durable, non-abrasive robust tile, yet also acting as a thermal and moisture barrier. An added value of the proposed tile is its acoustic property, where the shredded rubber makes it also resilient to impact and airborne noise. Its light colour also proves ideal for solar-exposed flat roofs, where, it is also aesthetically pleasing for the outdoor evening lifestyle in a Mediterranean climate.

INTRODUCTION

Since prehistoric times human beings have always searched for ways to protect themselves against the elements, first through the use of naturally formed shelters such as caves and then evolving into proper building-shaped constructed dwellings made using either naturally occurring materials extracted from the earth or man-made artificial materials. Through time, with the introduction of energy-intensive heating and cooling systems, energy consumption in buildings has however increased. This is requiring that new methods for making a building more energy efficient be researched and studied.

In this context, particular attention is being given by researchers not only to provide building elements with good thermal properties, *e.g.* low thermal transmittance which prevents high rates of heat transfer, but also to the fact that these building elements are made from materials, possibly recycled ones, having a low embodied energy. One such material is recycled rubber from end-of-life automotive tyres. Due to the heavy metals they contain, rubber tyres are a very problematic waste source. If disposed incorrectly, the chemicals they contain can contaminate ground water sources. Also, other problems arise from their size which makes it very hard and expensive to dispose of. To minimise volume burning them is an option, however today this is practically forbidden due to the toxic gases discharged into the atmosphere (typically carbon monoxide and sulphuric acid). This problem is aggravated by the fact that each year millions of tyres are consumed to meet vehicle road standards. If properly recycled, this rubber however, can be made

Vincent Buhagiar and **Simon P. Borg** are respectively Professor and Lecturer in the Department of Environmental Design at the University of Malta, Malta. **James Bonnici** is a practicing architect and civil engineer.

to good use given its inherent thermal properties, which give it a low thermal conductivity value, ideal for use in building components.

Recycled Rubber Embodied energy

Material selection and technologies used in building construction should aim to achieve the building occupants expected performance as well as aiming to minimise the environmental impact as much as possible, not only in the context of reducing energy consumption during its lifetime, but throughout its lifecycle, starting off from its production to the time when it is disposed off. In this context, Table 1 shows the specific total embodied energy per kilogram of tyre material produced. The rubber used for the production of tyres has a very high embodied energy and therefore finding alternative uses, especially at the end of lifecycle, can be beneficial to the environment.

Table 1. Embodied energy and greenhouse emissions of manufactured rubber tyre

Material	**Energy (MJ/kg)**	**Greenhouse (kgCO_2/kg)**
Natural Rubber	8	0.4
Synthetic Rubber	110	5.0
Carbon Black	125	5.7
All other additives	100	8.2
Fabric	45	2.1
Steel Tyre Cord	36	3.2
Manufacture per kg	11.7	1.86
Total	**435.7**	**26.46**

Recycled Rubber as a Building Material

The use of recycled rubber as a building material is not something completely new and various attempts have been made to make use of this resource to improve the properties of a building element.

Recycled Rubber as Asphalt A study made by the University of Toronto (Way *et al.*, 2011) was carried out to investigate the use of recycled shredded rubber in normal road asphalt. Metro Toronto Roads and Traffic Department resurfaced five main roads using this new mix and no serious difficulties were encountered. In actual fact it was noticed that the new roads offered a greater durability with a lower requirement for maintenance and a subsequent higher expected lifetime, and a better overall performance with respect to road safety due to a higher frictional response (Piggott and Woodhams, 1979).

Recycled Rubber Floorings Rubber floorings is another use for recycled tyre rubber. Floor tiles made using recycled rubber are relatively soft, despite them being used for commercial grade durability standards. Such properties in fact render these floor tiles a particular viable option for flooring systems in retail outlets were people walk for long periods of time and in playrooms and public spaces where the impact absorption properties of such floor tiles, adds an element of safety for children playing in these spaces. Gyms also often use this product as it absorbs sound made from falling weights and the continuous uses of cardio machines. Finally, rubber floorings can also be used in bedrooms and other living spaces as an alternative to fitted carpets (Ecosurface, 2014).

THE NEW BUILDING ELEMENT PROPOSED

The aim of this research was to create a new type of roof tile using recycled material generated from vehicle worn out tyres and inert demolition waste, originally both intended to be disposed of, and both requiring large volumes at waste disposal facilities. In warm climates where flat roofs are the norm, solar ingress through the roof is a main source for heat gains inside buildings, since these receive the beating of a persistent scorching sun in summer, unlike walls that could be typically shaded. Therefore the provision of thermally isolating materials as part of roofing elements is of primary importance for reducing such solar gains. This is particularly important in a hot Mediterranean Island such as Malta.

Element Composition

Aerated concrete was used as the base material with shredded rubber from recycled tyres added in varying percentages, namely 20%, 30% and 60% to constitute different tile mixes. Aerated concrete, classified as a lightweight concrete, is made up by mixing concrete with an aerating agent which causes the creation of a number of air voids inside the mix. The main advantage of this type of concrete is its lightweight composition and the high degree of thermal resistance which reduces the need of adding extra insulation to improve the thermal performance of a building element. The tile, having dimensions of 300mm by 300mm, was finished with a thin layer of a glass fibre coating. Polyester resin fibreglass is an impermeable material, thus adding this element would benefit the tile from making it water proof. Another added benefit of the fibreglass finish is in terms of its strength. Since the fiberglass contains and supports the aerated concrete which is considered to be weak, due to the presence of a large amount of air cavities, the tile performs better with regards to flexural strength, as the fibreglass encloses the tile creating a more compact system of materials.

SPECIMEN BUILDING AND TESTING

This section focuses on the procedure adopted in building and testing the proposed tile using a parametric methodology, whereby a number of design mixes were produced to analyse the effect of a selection of parameters on the thermal performance of the tile.

Test Specimen Preparation and Construction

Preparing the specimen involved using a mixture of recycled rubber granules, sand, cement and water to create the base constituents for the recycled rubber-infused aerated concrete mix. For the aeration process aluminium powder and sodium hydroxide were then added. In order to allow enough time for the aeration process a popular retarder was added to the mixture, to slow down the cement hardening reaction process. Once the mixture was prepared and the aeration process started, the tiles were left for two days to set within a specially designed mould. Once ready the moulds were dismantled revealing the tile. A fibreglass coating of around 4mm thickness was applied at the end of the process to give the tile a smooth clean dust-free, cream-white finish. Figure 1 shows a schematic of the different layers of the tile (inverted).

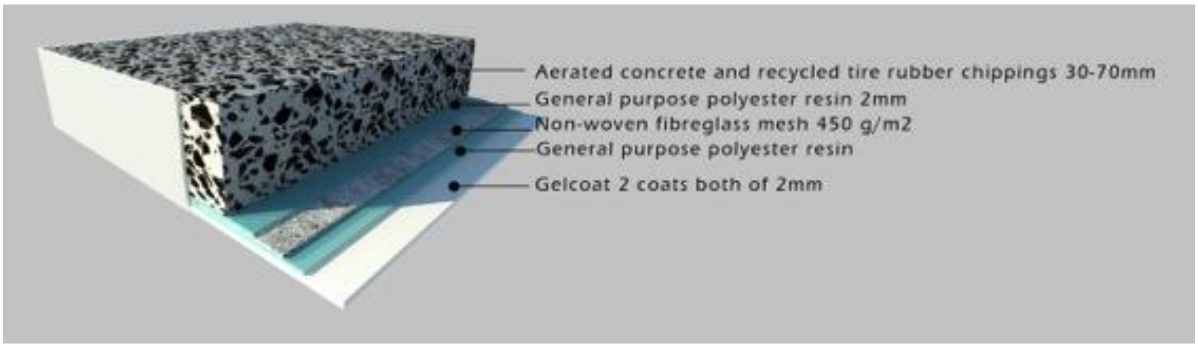

Figure 1 Schematic of propsed tile (inverted as cast)

Testing the different design variables

As part of the testing procedure various design mixes were produced with the intent of testing the variability in thermal performance of the different proposed design variables. The main variable parameters tested were the rubber percentage and the tile thickness, with each variable being tested for three possible permutations for a total of nine combinations. The rubber percentage was varied between 20%, 30% and 60% of the design mix. For each rubber percentage three tile thicknesses were moulded, namely 45mm, 70mm and 90mm thickness. Table 2 summaries the different combinations created.

Table 2. Tile Mix Material Values

Rubber Percentage (%)	*Thickness (mm)*	*Sand (g)*	*Cement (g)*	*Water (g)*	*Rubber (g)*	*Aluminium (g)*	*Sodium Hydroxide (g)*	*Retarder (g)*
20	**45**	2	900	54	460	22	22	15
30	**45**	2	820	49	690	20	20	12
60	**45**	1	615	37	960	17	17	10
20	**70**	3	1200	72	640	32	24	17
30	**70**	3	1150	69	900	30	22	15
60	**70**	2	900	54	1380	22	20	13
20	**90**	4	1780	10	920	46	35	22
30	**90**	4	1650	99	1290	44	32	20
60	**90**	3	1300	78	2016	34	25	18

Testing inside the Hot Box

The testing of the tiles was carried out using an established insulated Hot Box previously used and tested in the Environmental Lab. This was originally built according to BS EN 8990:1996 (BSI, 1996). The Hot Box was constructed using concrete block work, filled with C30 concrete with all joints sealed to reduce any heat losses. In order to measure the overall heat transmittance (U-Value) of horizontal building elements the Hot Box is divided into two chambers, a controlled artificially heated '*hot*' chamber and an underlying '*cold*' chamber, separated by a typical Maltese roof construction, as shown in Figure 2.

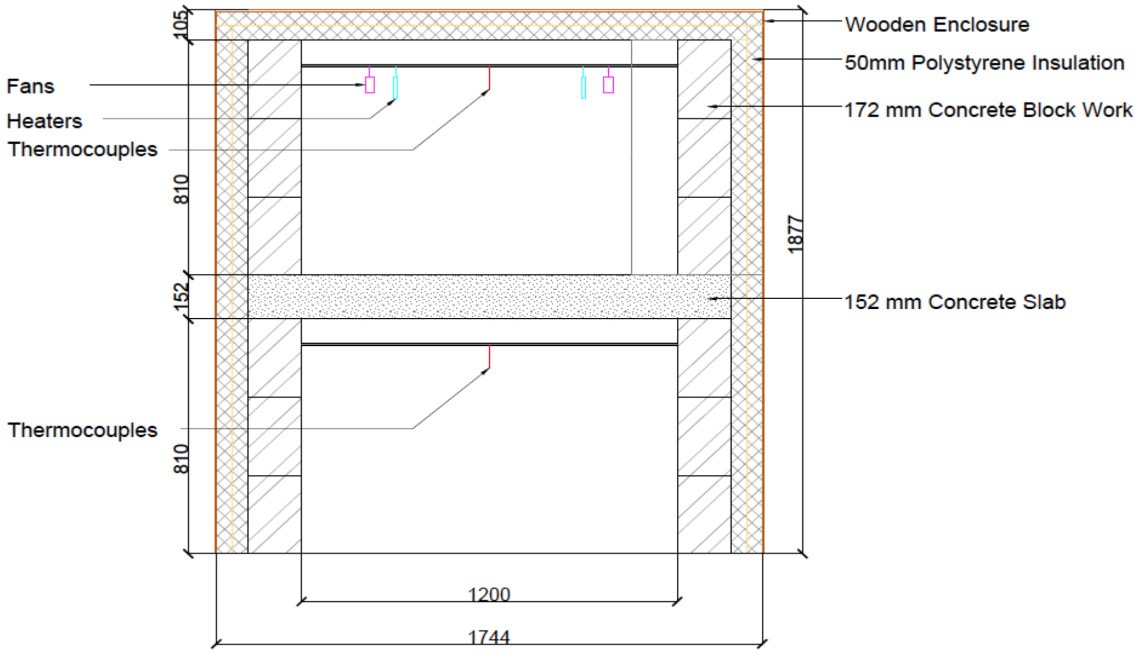

Figure 2 Sectional Elevation of the Hot Box

The top-most warm side of the Hot Box was set up with four heaters, grid-lined, each having a power of 700 Watts suspended from a steel square mesh connected to the top part of the Hot Box, as the gridmatrix. Four fans were also connected to the mesh to create a continuous air flow thus creating an evenly distributed temperature profile throughout the interior warm side of the Hot Box.

Each combination of designed tile mix was tested inside the Hot Box, by laying the tiles on top of the '*hot*' chamber floor, as shown in Figure 3, and measuring the temperature difference between the two chambers once steady-state is obtained.

Figure 3 Hot Box set-up comprising the composite tile, 50mm globigerina sand, damproof membrane

In order to measure the temperature difference across the two chambers a total of 18 thermocouples were used. In the top '*hot*' chamber, eight thermocouples were fixed on top of the tile surface while a ninth thermocouple was suspended in mid-air to measure the air temperature inside the chamber. The setup was mirrored in the '*cold*' chamber. Each thermocouple was connected to a central data logger which recorded the readings from each individual thermocouple. The ambient room temperature was also monitored.

Surface temperature readings were recorded at 15-minute intervals until a until the hot box reached steady state i.e. the temperature gradient between both chambers remains at a constant rate. Once the hot box reached this thermal status, the steady state the temperature difference was calculated.

The composite tiles laid and tested into nine different categories. Each category had sixteen similar tiles, (4x4no.x 300mm each tile), fitted in the calibrated hot box. Each category has a variation in either thickness or rubber content as indicated in subsequent output results, Figure 4.

RESULTS

Figure 4 shows how the overall heat transmittance, the building's element U-value, as it varies with respect to changes in the recycled rubber content and the tile thickness. It can be observed that the major governing factor in decreasing the U-value of the proposed tile is by varying the thickness. As the thickness increases the lower is the U-value obtained. Increasing the rubber content also decreased the U-value but to a lower extent.

The main advantage of this design mix is that the rubber can be used to increase the volume of the tile, replacing quarried limestone sand, thus saving embodied energy, with the added benefit of making the tile more thermally resistive. With an increase in rubber content from 20% to 30%, the U-value dropped by -0.05, -0.06 and -0.13W/m^{2}K for the 45, 70, 90mm tiles respectively. With an increase from 30% to 60% further drops of -0.07, -0.02 and -0.03 W/m^{2}K were noted for the 45, 70, 90mm tiles respectively, as can be seen in the summarised values in Table 3.

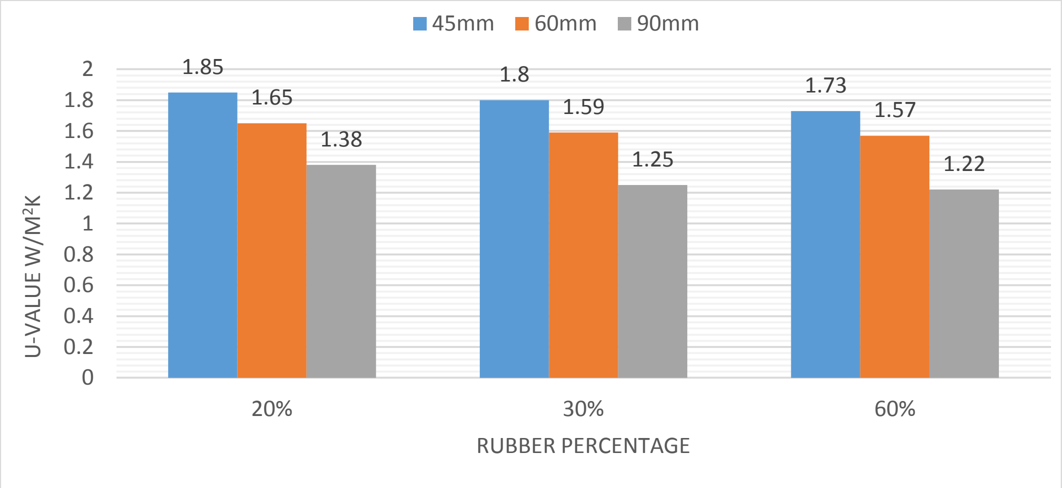

Figure 4 U-value vs. Percentage rubber content for the 45mm, 60mm, and 90mm thick tiles

Table 3. Percentage Rubber content *vs.* Tile Thickness & respective U-values

Rubber Ratio	**20%**	**30%**	**60%**
45mm tile	1.85 W/m^{2}K	1.80 W/m^{2}K	1.73 W/m^{2}K
Change in U-value		-0.05	-0.07
70mm tile	1.65	1.59	1.57
Change in U-value		-0.06	-0.03
90mm tile	1.38	1.25	1.22
Change in U-value		-0.13	-0.03

This further indicates that with a change of mass the drop in U-value is more pronounced than with the increase in rubber percentage. Moreover, an increae in rubber content with an increase in thickness sees het U-value drop by -0.13 W/m^{2}K. Although no further increases in %rubber or thickness was made, by extrapolation results indicate that the U-value would decrease further. An increase in mass would evidently increase its embodied energy and its cost given the greater mass per unit volume ratio. Such results can only be obtained through further studies or prediction modelling.

CONCLUSION

Currently Maltese building construction norms are slow to adhere to building regulations, technical guidance document part F, even though it has become national law. Most of the traditional Maltese roof constructions never had insulation since their thermal mass, composed of composite limestone strata in different forms, did the job reasonably well. Admittedly comfort standards were also less sttingent than today, with older folk and farmers leading an outdoor life more than ever.

In warm climates where solar gains through flat roofs is a predominant heat source, roof insulation is a necessary requirement to reduce heat absorption into the building. This should reduce cooling loads particularly given the increase use of fossil-energy based HVAC systems. Based on this premise the use of the novel recycled rubber tiles reduces the overall U-value of the roofing element. Moreover, the benefit of using a material such as recycled rubber and inert waste, both with a high embodied energy content, means that there is also a lower demand for quarried limestone sand as a raw land-based resource. This is certainly one added value of using such tiles as insulation or as a complement to it to say the least. Waste rubber tyres are also shredded for re-use rather than dumped, taking precious voluminous space. So this is already a win-win scenario from a waste management perspective.

The objective of this paper was to create a new, thermally insulating roof tile made from recycled rubber as a replacement or complement to any insulating material. It can be laid on roofs and open terraces over habitable spaces, thus increasing the energy performance rating of buildings, particularly dwellings.

SCOPE FOR FURTHER RESEARCH

Parametric tests were performed to test the best percentage ratios in the mix design composition of the tile. From results obtained the newly designed tiles generally increase the thermal efficiency of the building. By increasing the thickness and also the rubber content of the tiles, the average range of U-values obtained scaled from 1.85 to 1.22 W/m^2K. This is still higher then the minimum requirement for thermal transmittance allowed ofr roof structures in Malta, that is, 0.59 W/m^2K (Technical Guidance Document, Part F, of the Building Regulations of Malta).

Although results are already promising, unless a very thick tile is used one would not achieve sufficient reductions in thermal transmittance therefore testing the tile further is recommended with the addition of complementary insulation. More work also needs to be done on varying the basic parameters, namely the design mix of rubber to sand ratio, beyond 60%, as well as the thickness of a tile over 90mm. Another area to be delved into is the aerated concrete itself, where a greaeter porosity brings with it a greater insulating property; hence modifications to the design mix can be tested. Different types of rubber as well as its granulated size (larger granules to pulverised) is also worth investigating. Moreover, the tile's abrasive resistance, inherent durability, and its resistance to moisture are among a few other areas within the scope for further research.

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