PARAMETERS AFFECTING THE ALBEDO EFFECT IN CONCRETE

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Abstract
This paper presents a review of ongoing research at Trinity College into the parameters which affect the albedo effect, that is, solar reflectance of concrete. Some previous research by others considered the effect of the composition of concrete on the solar reflectance. Extending this work, the objective of this research is to quantify the improvement in albedo in concrete containing different aggregates and ground granulated blast furnace slag (GGBS) of varying proportions for different types of concrete finish. The subsequent change in light reflectance and heat absorption will allow one to establish the equivalent reductions in CO_2 by virtue of reduced air conditioning costs in buildings, reduced heat emissions from warm surfaces and increased light reflected back into the universe.

Three aggregate types will be used (crushed limestone, partially crushed limestone and sandstone) with four different percentages of GGBS (0, 30, 50 and 70%). There will be four different surface finishes each to represent certain applications such as a roof area, pavement or car park. A number of devices will be compared in determining an albedo value including a lux meter, solar reflectometer, thermocouples and infrared camera.

Some preliminary research has been conducted to investigate the potential for the use of high solar reflectance concrete within the Trinity College campus. It was found that although the potential surface area which could be used is relatively small (one-third of the total), the corresponding offset in carbon dioxide emissions could be significant (approximately 4,000 tonnes per year).

Keywords: Aggregate types, albedo, carbon dioxide emissions, GGBS, reductions in CO_2, solar reflectance, surface finish

1. Introduction

Solar radiation includes visible light (typically 43% of solar energy), near infrared light (52%), and ultraviolet light (5%). Albedo is the ratio of reflected solar radiation to the total amount that falls on a surface, known as incident solar radiation (ACPA, 2002) and is measured on a scale of 0 to 1. An albedo value of 0 indicates a "black" body that does not reflect any light whereas an albedo value of 1 indicates a "white" perfectly reflective surface (Boriboonsomsin and Reza, 2007).

In developed urban areas, paved surfaces (footpaths, car parks, pavements) account for a large percentage of the total surface area, typically between 30% and 40% (ACPA, 2002). Dark materials such as asphalt 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 and infrared radiation to be reemitted. As the surfaces become warmer, the local ambient air temperature also increases. Where air and surface temperatures are warmer than their surrounding areas, this can create a 'heat island' (Gartland, 2008). The heat island effect can cause a number of problems including increased energy demand to cool buildings, which results in large air conditioning bills and an increase in emissions from power plants. It also increases the formation of smog as a higher temperature induces higher rates of photochemical reactions.

In order to reduce the heat island effect by reducing the temperature of the paved surfaces, it is necessary to increase the albedo, or solar reflection. One method would be the use of high solar reflectance concrete as concrete is lighter in colour than asphalt - grey Portland cement concrete typically has an albedo of approximately 0.35 (compared to 0.05 for asphalt). However, by altering the composition of the concrete it is possible to increase this value, in particular by substituting the grey cement with GGBS, which is substantially lighter in colour. Some typical albedo values are given in Table 1.

Table 1 - Typical albedo values (ACPA, 2002)

Surface	**Albedo**
Snow	0.90
Ice Caps	0.80-0.90
White Acrylic Paint	0.80
GGBS Concrete (50%)	0.50
New Concrete (traditional)	0.30-0.40
Aged Concrete	0.20-0.30
Roof Area	0.20
Aged Asphalt	0.10-0.15
Ocean	0.06-0.10
New Asphalt	0.05
Black Paint	0.05

Carbon dioxide is a greenhouse gas and it tends to block radiation from the earth's atmosphere. Prusinski et al. (2004) conducted research into the carbon dioxide emissions arising from the use of cement and its embodied energy. Although cement makes up only 10% to 20% of the concrete mixture, the cement is responsible for up to 85% of the total embodied energy and 94% of the carbon dioxide emissions.

In order to produce one tonne of Portland cement, approximately 0.9 tonnes of carbon dioxide is generated. GGBS requires nearly 90% less energy to produce than an equivalent amount of Portland cement and the production of carbon dioxide during the manufacture of GGBS is practically negligible. Prusinski's research is confined to substitution rates of between 35 and 50% GGBS.

2. Materials and Methods

2.1 GGBS

GGBS is a waste product from the blast-furnace production of iron from ore and is used to replace cement in concrete structures. As GGBS is significantly lighter in colour in comparison to conventional Portland cement (Figure 1), its inclusion in concrete subsequently produces a concrete which is lighter in colour. A lighter coloured concrete surface has increased solar reflectivity which results in brighter environments. This increases visibility especially at night time, leading to reduced lighting by approximately 30% (Riley, 2008) and improves safety (SCA, 2003). As it has a higher albedo value it can help to reduce the heat island effect and this can result in achieving LEED (Leadership in Energy and Environmental Design) credits (SCA, 2006). This is a national standard developed by the United States Green Building Council which rates a building's environmental performance and the use of GGBS can have a positive effect on a number of the credit categories. This is the US equivalent of BREEAM in the UK.

Figure 1 - GGBS and Normal Portland Cement (Ecocem, 2009)

A preliminary study carried out by Boriboonsomsin and Reza (2007) using 30%, 60% and 70% GGBS replacement showed that concrete with a high cement replacement achieved a higher albedo. The crude relationship between the albedo and the level of replacement of cement with GGBS can be seen in Figure 2. Although the simplistic approach gives an indication of the effect of GGBS addition, other parameters also affect the albedo value, including concrete moisture content, aggregate type, curing conditions, surface finish and age. These parameters are the focus of the present study.

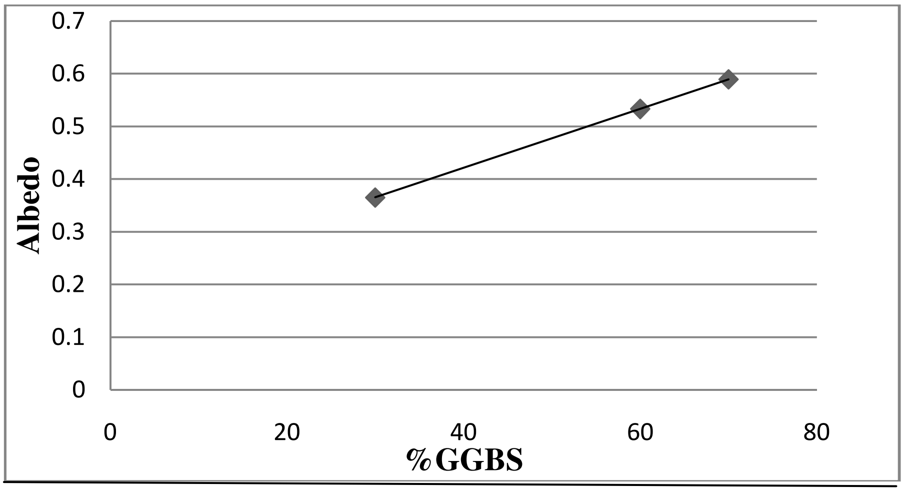

Figure 2 - Relationship between albedo and GGBS content of concrete (Boriboonsomsin and Reza, 2007)

Greyness of Cement

The albedo of concrete made with Normal Portland Cement ranges between 0.20 and 0.40 and can be seen in Table 1. However, as GGBS is much lighter in colour than Normal Portland Cement (Figure 1), its addition increases the albedo value to between 0.40 and 0.60 depending on the substitution rate (Figure 2).

As a result and as part of this study, a colour card will be produced with a wide spectrum of greyness from a white surface to a black surface. The albedo result will then be converted into equivalent reductions in CO_2 emissions.

2.2 Methods

The main aim of this study is to demonstrate enhanced albedo of GGBS concretes compared to a reference concrete with no GGBS present for different concrete constituents and finishes. These mixes will consist of a commonly used cement, CEM II/A-L, with 0%, 30%, 50% and 70% GGBS.

The samples will also comprise three different aggregate types; crushed limestone, partially crushed limestone and sandstone. Different surface finishes will be applied to represent different application types, namely footpath, roof, car park and road areas, thus the surface finishes to be used will be brush, screeded, trowelled and tamped respectively (Table 2).

Table 2 – Proposed testing parameters

	Aggregate 1 Crushed limestone				**Aggregate 2 Partially crushed limestone**				**Aggregate 3 Sandstone**			
	GGBS Level (%)											
Application/Finish	**0**	**30**	**50**	**70**	**0**	**30**	**50**	**70**	**0**	**30**	**50**	**70**
Footpath	X	X	X	X	X	X	X	X	X	X	X	X
Roof	X	X	X	X	X	X	X	X	X	X	X	X
Car Park	X	X	X	X	X	X	X	X	X	X	X	X
Road	X	X	X	X	X	X	X	X	X	X	X	X

The slabs will be 400 x 400 x 60mm in size and there will be two slabs manufactured for each matrix input for repeatability purposes. Thermocouples will be placed in the slabs and once the slabs are poured they will be exposed to a strict and consistent curing regime for the first 24 hours and cured in the air subsequently. They will be placed on a rooftop to be exposed to the environment over the course of at least one year.

2.3 Mechanisms of Measurement

Four independent means will be employed to evaluate albedo. Based on this a recommendation will be made as to the preferred method for measurement.

Temperature

Thermocouples will measure the increase in temperature both on the surface of and inside the samples when exposed to natural sunlight. The ambient temperature will be measured in close proximity to the sample as a reference point. This is being used to independently evaluate the solar light absorption.

Heat Absorption
A thermal imaging camera will be used to measure the uniformity and differences in heat absorbed by the samples once exposed to natural sunlight. The camera records the emittance of infrared radiation from hot bodies and so complements the direct temperature measurements.

Solar Reflectance/Albedo
A portable solar reflectometer will be used to measure the solar reflectance of the samples - this measures the ability of the sample to reflect sunlight off the surface. This is the only method which measures the albedo directly. The samples will be exposed to the environment once placed on the roof, so aging of the samples will be monitored by measuring reflectance at monthly intervals up to one year in order to establish the rate of deterioration of albedo over time.

The reflectometer will obtain measurements of reflectivity at certain wavelengths which can then be integrated to obtain an albedo value. Taha et al. (1992) carried out this procedure which is done by weighting the reflectivities by intensity at each wavelength in order to produce a representative albedo value. This method requires only a small surface area.

Lux Meter
A measure of the light intensity which exists can be achieved by using a lux meter. This measures light in units of "lux" (lumens/m^2) and for light reflected off a surface is an indirect indication of the level of albedo.

Moisture Content
Levinson and Akbari (2002) found that wetting the samples altered the albedo value therefore this parameter will be measured. The greyness of a concrete surface depends to some extent on its dryness - wet surfaces appear darker. To eliminate this parameter, a moisture meter developed by Tramex Ltd. (Holmes and West, 2002), which measures the near surface moisture conditions, will be used on each occasion albedo is measured.

3. Preliminary Research

3.1 Potential for comparison of flat horizontal surfaces

Method
As part of a project to convert Trinity College campus into a greener environment, a study was undertaken into the potential effect of albedo changes to exposed horizontal surfaces on campus.

The objectives were as follows:

- To consider the conversion of four main elements of the campus, namely footpath, roof, car park and pavement areas into whiter surfaces.

- To quantify the total possible surface area within the college which could contain brighter surfaces with the expectation of increasing the overall albedo of the college but without impinging on its historical integrity.
- To calculate the corresponding CO_2 emissions which could be offset as a result.

There are various ways in which to increase the solar reflectance of a surface and one such method is the use of high solar reflectance concrete as described previously. A map of the campus was obtained and the various areas were calculated from this, broken down into categories such as green areas, concrete areas, asphalt car parks, asphalt pavements, asphalt footpaths, horizontal roof areas and miscellaneous.

It was found that just under one-third of the college consisted of green areas, one-third roof areas and the remaining one-third consisting of cobbled areas, asphalt and concrete/paving areas (Figure 3). The asphalt and the concrete/paving slabs around the campus make up 20% of the total surface area. These areas, in conjunction with the roof areas, make up approximately 53% of the campus.

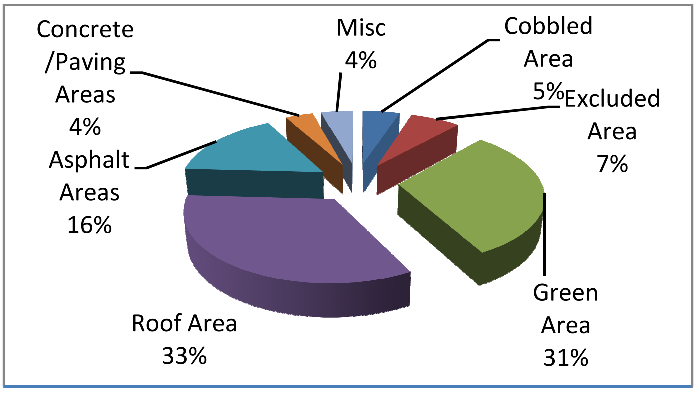

Figure 3 - Breakdown of horizontal areas in Trinity College Dublin

However, of the areas calculated, as demonstrated in the pie chart in Figure 3, there is only 33% of surface area within Trinity College Dublin which has the potential to be used to increase the albedo of the college as areas such as green areas and cobbled areas are excluded. In order to calculate the offset of CO_2 emissions, the current albedo value of the surface in addition to the possible increase in albedo value is required. By using Dublin as a geographic location with an average annual solar radiation, the combined CO_2 saving from the various surfaces within the college was found to be 4,056 tonnes per annum, with the roof area being the largest contributor at 41%. This calculation was based on the increase from the current albedo (ranging from 0.10 to 0.25) to an albedo of 0.60 and was based on research carried out by Akbari et al. (2008). This indicates a potential for CO_2 saving, even on the 40 acre site.

3.2 Test Apparatus for Demonstrating Light Reflection

Before embarking on an extensive testing program, it was necessary to confirm the likelihood of being able to discern changes in albedo of the various concrete specimens. An apparatus was constructed whereby samples of concrete with varying percentages of GGBS (0, 50, 70 and 90%) could be tested with a lux meter to determine the amount of light reflected by the sample. Rectangular prisms (160 x 40 x 40mm in size) are placed in the apparatus in Figure 4. They are inclined at an angle of 45°. A light meter is placed on top of the apparatus which previously had a circular hole cut that was the exact diameter of the light meter receiver so as to exclude peripheral light entering. The receiver on the light meter is parallel to the specimen's surface. The apparatus' surfaces are black inside to exclude any background light. Artificial or natural light enters the front of the testing apparatus and is reflected off the surface of the sample and up towards the light meter where a reading is taken.

This apparatus demonstrated that for each increase in the percentage of GGBS, there was a corresponding increase in the amount of light reflected off the surface which could be seen from the readings on the lux meter. These values ranged from approximately 40 to 75 lux which indicates a reasonable range despite the relatively small reflective surface of the prism. A more refined device is being developed for the specimens listed in Table 2.

Figure 4 - Test apparatus for demonstrating light reflection

4. Conclusions

Albedo, or solar reflectance, is defined as the ratio of reflected solar radiation to the total amount that falls on a surface. The albedo value varies between 1, where 100% of the incoming radiation is reflected, to 0, where no radiation is reflected and it is all absorbed by the surface. Consequently this raises the temperature of the surface and the solar radiation is reemitted as infrared radiation or as heat. A typical surface with a high albedo value would be fresh snow (0.90) and an example of a dark surface with a low albedo would be new asphalt (0.05).

A high albedo concrete surface can be achieved by using a cement replacement such as GGBS which is lighter in colour than Normal Portland Cement. However there are a number of factors which affect the albedo value such as the level of cement replacement, aggregate type, surface finish and the curing regime. As there will be a number of specimens manufactured in order to determine the effect of these parameters, they will be evaluated at regular intervals over the coming year to determine the effect of aging also.

During some preliminary research, the layout of Trinity College campus was examined in order to determine if there were any potential horizontal areas where the albedo value could be increased and to calculate a corresponding offset in carbon dioxide. It was found that a small percentage (33%) of the total area within college could improve its albedo, with the majority of this area being roofs. This would result in an approximate equivalent saving of 4,000 tonnes of carbon dioxide per year.

An experimental apparatus was set up to demonstrate the principle of solar reflection on a GGBS concrete surface using artificial light. A lux meter was used to measure the amount of light reflected off a number of rectangular prism samples containing different levels of GGBS. The results varied between 40 and 75 lux. This confirms that the samples with a higher percentage of GGBS have a higher albedo value and that a lux meter can be used to establish this reliably and repeatedly. This concept will be used in developing the research further.

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