Determination of reflectivity of concrete slabs applied with paint added with powdered *Placuna placenta* shell as additive

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Abstract

Retroreflectors are used as additives to paint in order to increase their reflectivity. A typical example would be glass beads whose vitreous luster and spherical shape make them efficient retroreflectors. These properties allow any surface where it has been applied on to absorb less heat and reflect more light. *Placuna placenta* shells are vitreous and can be powdered into spherical shape which can serve as efficient retroreflectors. The shells were ground into powder, sieved and then added with varying ratios to commercial white paint before being tested if they still pass the national paint standards. Each paint setup was tested for its albedo and temperature to determine its reflectivity. Results revealed that even after adding the *Placuna placenta* shell powder to the commercial paint, all modified paints still managed to meet the national standards for paint tests. Analysis of the photos taken of the setups showed that those with the highest ratio of shell powder exhibited significantly higher reflectivity. The temperature difference between setups, however, was not statistically significant. Therefore, powdered *Placuna placenta* shells can be used indeed as a paint additive and that it increases the reflectivity of the paint.

***Keywords**: Placuna placenta, solar retroreflector, paint additive, paint tests, reflective paint*

Introduction. Retroreflectors are substances that reflect light at an angle back to the source [1]. A prominent example would be glass beads, which are used as paint additives as its vitreous luster and round shape allow the surface to reflect more light. This means that the surface it is applied and painted on would absorb less heat and lower its temperature [2]. Glass beads, however, can be substituted with a locally sourced abundant material *Placuna placenta*, locally known known as Capiz shells, which are notable for their glasslike properties.

P. placenta are bivalve mollusks with protective shells that are found in South and Southeast Asia and are especially abundant in the Philippines. The Department of Environment and Natural Resources (2003) reported that the Philippines exports 2100t to 4000t of raw *P. placenta* shells to 41 different countries yearly, making it the world's largest supplier of the material. While it is used as a glass substitute due to its unique features among the different species of bivalves [3], this substitution is mostly aesthetic in nature. This study aimed to maximize the potential use of the shells by utilizing their unusual characteristics. The shells are 98% mineralized, mainly of calcite, which exhibits a vitreous luster [4]. Furthermore, powdering it would give it a spherical shape [5], giving it the properties that makes glass beads efficient retroreflectors which makes them a viable candidate as a paint additive to increase reflectivity.

Paint, the type of coating which is commonly applied over concrete structures, is composed of a solvent, a resin or binder, pigments, and additives. Additives are components that are used to enhance certain properties of the paint [6]. Paint can also be engineered in such a way to reduce heat transfer and surface temperature through the use of specific pigments that minimizes the light absorbed [7]. Powdered calcite is used as a component of paint, either as a binder or a substitute for Titanium Dioxide [8].

By increasing the albedo or the surface reflectivity of the paint over the concrete using *P. placenta* shells, the study aimed to cause the slab to reflect more light and heat, lowering the surface temperature. If successful, the findings of the study can be used to mitigate the urban heat island effect, a phenomenon used to describe the significantly higher temperatures of urban areas in comparison to the surrounding rural areas. When buildings use roofs with high reflectivity, energy consumption for cooling devices is reduced, thus the need for retroreflectors as additives [9].

The objective of this study is to determine and compare the albedo and temperature of concrete slab applied with commercial paint, with and without powdered *P. placenta* as additive after being subjected to paint tests. It specifically aims to:

(i) To determine the density, specific gravity, extraction of pigment, drying time, volatile matter, and Titanium Dioxide content of the paint to be used.

(ii) To determine and compare the percentage of light reflected by the concrete surface applied with paint, with and without *P. placenta* shell powder additive.

(iii) To determine and compare the temperature of the surface applied with paint with and without

P. placenta shell powder additive over a period of time.

Methods. The whole study was executed in the province of Iloilo, Philippines from February to May 2018. Five setups with differing amounts of solid composition according to the amount of *P. placenta* shell added, each with three replicates, was used for the study. Each set-up consisted of a concrete slab covered with two coatings of a commercial, non-gloss, latex white paint (38% solid composition) with varying ratios of *P. placenta.* Samples were then photographed using an android smartphone camera and an albedo application was used to quantify the amount of light reflected. The test slabs were basked under the sun for 5 hours and the surface temperature of the concrete slabs were then measured on a 30-minute interval [10] using a thermogun.

Concrete slab construction. Fifteen 30.48 cm x 30.48 cm x 8.00 cm [10] concrete slabs with an approximated strength of 4000 psi were constructed by a contracted party, under the supervision of the researchers. It used a ratio of 2:3:6 part cement, sand, and gravel, respectively.

Paint Acquisition. A generic commercial paint was bought from a local hardware store. The commercial paint used was a non-gloss, flat latex white paint.

Acquisition and Powdering of P. placenta Shells. P. placenta shells were collected from a shell bed in Oton, Iloilo (10°39'45.2"N 122°26'48.2"E). The shells were washed in distilled water. They were heated over a low flame of not over 100°C to induce the opening of the bivalve. The shells were rinsed with distilled water before being subjected to open air drying. *P. placenta* shells were crushed using a homogenizer into fine powder, which was then sieved through a 250 µm laboratory stainless steel sieve.

Addition of Powdered P. placenta Shells to Paint. According to the Rohm and Haas Paint Quality Institute, a high-quality paint typically has 30 to 45 % solid composition by volume which can reach up to 50%. Since the base paint is already at 38% solid composition and it could cap at 50%, the increments were set at 4% in order to have three modified setups. This resulted in the solid composition of 42%, 46%, and 50% for the modified paint with powdered *P. placenta* shell as additive. Each one has a total volume of 1.0 L with different ratios of paint and powdered *P. placenta* as seen in Table 1. This was done by measuring a set amount of *P. placenta* in the 50-mL beaker and determining its mass to figure out the density. From this density, the mass of the powder was measured using a triple beam balance (Triple Beam Balance 700 series 2610g 09) to acquire the needed volume instead of using a beaker. The measured powder, as shown in Table 1, were added to the freshly opened 1.0 L cans of paint were stirred until thoroughly mixed.

Acquisition of Necessary Equipment and Request of Testing Site. Albedo: Reflectance App™, an albedo testing application was downloaded to a smartphone with 13-megapixel camera. Triple beam balance and sieve were requested from the school's research laboratory. Other materials and equipment like beakers and containers were borrowed from the paint testing laboratory of the Department of Public Works and Highways Region VI (DPWH VI) or bought from Patagonian Enterprises.

Quality Testing of Paint with P. placenta Powder. Paint testing was conducted in the paint testing laboratory of DPWH VI. The paint mixtures were tested for their density, unit mass, drying time, pigment analysis, total solids and percent Titanium dioxide in adherence to the DPWH paint test procedures.

Table 1. Different ratios of paint and powdered *P. placenta*

Setup	Features	Ratio
A	Coated with ordinary white paint	1.0 L paint
B	Coated with ordinary white paint with *P. placenta* applied over it by evenly sprinkling using a sieve.	1.0 L paint with 148.1481 ml powdered *P. placenta*
C	Coated with ordinary white paint with *P. placenta* (42% solid volume)	1.0 L paint with 68.9655 ml powdered *P. placenta*
D	Coated with ordinary white paint with *P. placenta* (46% solid volume)	1.0 L paint with 148.1481 ml powdered *P. placenta*
E	Coated with ordinary white paint with *P. placenta* (50% solid volume)	1.0 L paint with 240.00 ml powdered *P. placenta*

Painting and Application of P. placenta. The concrete slabs were each coated with their designated mixture and *P. placenta* as specified (Table 1) using a paint roller. In Setup B, where the *P. placenta* shell powder is needed to be sprinkled, the powder was placed in the 250 µm sieve and shaken in a uniform motion all over the concrete cell.

Calibration of Smartphone with Albedo Application and Thermogun. A Samsung J7 Prime with a 13-megapixel camera that can run the Albedo: Reflectance App™ was used for the study. The application works by comparing the image of the sample with an image of a photographer's gray card as a calibrator (albedo of 0.18).

A Fluke Mini IR Thermometer (S/N: 18201385) was used to measure the surface temperature of the concrete slabs. The IR thermometer was calibrated using an ice bath, a container filled with crushed ice mixed with cold water. The IR thermometer was held directly above and perpendicular to the ice bath before taking the measurement which should read 0.0°C.

Albedo Analysis. The photos were taken of the setups were analyzed by the Albedo: Reflectance App. At consistent lighting, the findings show that a trend occurred where the setups with more *P. placenta* powder exhibited higher albedo. Setup B, whose shell

powder was sprinkled after painting and not mixed, had the highest values.

Field testing. The concrete slabs were placed in an open area with even lighting conditions. Using a 13-megapixel camera of a Samsung J7 Prime, photos were taken of the setups and were analyzed by the Albedo: Reflectance App™. They were then exposed under the sun from 11:00 to 16:00 (local time) and the surface temperature were measured using the thermogun in a quick-succession with an insignificant time delay between each slab at a thirty-minute interval. To get the best possible results, the thermogun was aimed on the geometric center of the surface of the slab, from a certain distance to make sure thermogun the reading cover as much of the slab as possible.

Data Analysis. The albedo and temperature changes in each test slab were statistically compared with each other to determine significant trends. For the analysis of albedo, t-tests were used to compare the unmodified setup to each of the other four setups in order to determine if there is a significant difference. One-way ANOVA was used to determine if there is a significant difference between the surface temperatures of the concrete slabs for each time interval. Tukey's Honest Significant Difference test, a post-hoc test, was used to further determine where the significant difference occurred.

Results and Discussion. The modified paints with powdered *P. placenta* shells still passed all of the required values. Even with the addition of the powdered shells, the paints were all still able to pass all the paint test values imposed by the Department of Public Works and Highways as shown in table 2.

The specific gravity of the paint refers to its density, which may depend on the pigments used. There is no maximum value for density but the paint should have a minimum density of 1.35 kg/L to ensure that there is enough pigment for the components to completely coat the surface after the dillutant have evaporated. There was almost no difference in the density values of the modified and unmodified paints, with all samples having a density of 1.44 and 1.45 kg/L which is significantly higher than the minimum value required. The difference in density between the paint and the shells was probably too small to make a significant change in its specific gravity.

The percentage of the total solids refers to the mass percentage of the solids left after the paint has dried. As expected, the paints added with powdered *P. placenta* exhibited the highest values, with the paint with 50% solid volume composition having 58.52% while the unmodified paint exhibited the lowest with 53.54% total solids. This is because the addition of powdered *P. placenta* shells increased the solid composition percentage of the paints.

The percentage of pigment extracted refers to the solids left after combustion. The higher the total solids, the higher the expected percentage of pigments. The paints added with powdered *P. placenta* still exhibited the higher values, with the paint with 42% solid volume composition having 54.05% while the unmodified paint exhibited the lowest with 44.90% extracted pigments. The volatile matter, meanwhile, refers to the percentage of solids that are not pigments and were combusted during the combustion process. Ordinary white paint exhibited the highest percentage at 20.06% while the modified paint with 50% solid composition had the lowest value at 18.59% volatile matter. The fact that the powdered shells are not volatile, and their addition meant that the percentage of volatile solids in paint decreased while their pigment extracted increased.

Paints that dry too fast means that it is too diluted while paints that takes too long to dry may have consequences on application. All the treatments managed to dry within the expected time, with the unmodified paint and the paint with 46% solid volume just drying shortly after 10 minutes while the paints with 42% and 50% solid volume drying just before 15 minutes. As drying time is usually attributed to the binder of the paint which remained unmodified, no significant difference was noted.

Titanium dioxide is a standard of quality paints as it effectively scatters light, imparting brightness and opacity in the coating. The modified paint with 42% solid composition resulted with the highest values at 40.57% of total pigments while the paint with 50% solid composition displayed the lowest values at 33.30% of total pigments. As the powdered shells

Table 2. Results of paint tests with the minimum or maximum standard value of properties.

Paint Test	Specific Gravity (kg/L)	Total Solids (%)	Extraction of Pigment (%)	Drying Time: Set to Touch (minutes)	Drying Time: Dry Hand (minutes)	Volatile Matter (%)	Titanium Dioxide Content (% by wt. of pigment)	Remark
Min Value	1.35	49	39	10	-	18	30	-
Max Value	-	-	-	15	60	-	-	-
A	1.45	53.54	44.90	10.30	16.97	20.06	37.22	Passed
C	1.44	56.68	54.05	14.30	22.30	19.85	40.57	Passed
D	1.44	57.32	52.27	10.00	14.33	18.62	33.58	Passed
E	1.45	58.52	50.96	14.67	18.00	18.59	33.30	Passed

were mainly of calcite [4] and do not contain titanium dioxide; they did not alter the percentage values of the substance in the paint. [11] Boke (2013) discussed how calcium carbonate or calcite is already used as a component of paint, either as a binder or a substitute for titanium dioxide.

The paint test results suggests that the addition of the *P. placenta* shell posed no complications and that was observed in this study as the modified paint with the powdered shells were still able to pass the paint test standards of DPWH. No other studies can be found, however, that conducted paint tests after the addition of retroreflectors to commercial paint and thus, no comparisons can be made with existing literature.

Table 3. Measured albedo of each setup.

Setup	Percentage of Light Reflected (Albedo)
Coated with ordinary white paint (A)	0.43
Coated with ordinary white paint with sprinkled *P. placenta* (B)	0.56
Coated with ordinary white paint with *P. placenta* mix (42% solid volume) (C)	0.45
Coated with ordinary white paint with *P. placenta* (46% solid volume) (D)	0.47
Coated with ordinary white paint with *P. placenta* (50% solid volume) (E)	0.51

Albedo. The albedo, or the percentage of light reflected by a surface was measured using Albedo: A Reflectance App™ and a 13-megapixel camera of a Samsung J7 Prime. The photos taken were analyzed by the Albedo: Reflectance App™. As hypothesized, the setups with more percentage of powdered *P. placenta* shells exhibited higher albedo, with the 50% solid volume modified paint reflecting 51% of the light while the unmodified paint only reflected 43% The setup coated with sprinkled *P. placenta* exhibited the highest albedo, reflecting 56% of the light, while the ordinary white paint exhibited the lowest, reflecting only 43% of the light. The findings are shown in Table 3 below.

These results show that the powdered shells successfully acted as retroreflectors and increased the reflectivity of paint. The more of the retroreflectors added to the paint, the wider the surface area it can cover and the more light it can reflect back. Additionally, by sprinkling it on top, it prevented the pigments of the paint from covering the retroreflectors, allowing more of them to come into contact and reflect light. In the study of Nguyen et. al. [10], it is the right combination of Titanium Dioxide and glass beads that yielded the most retroreflectivity but in general, the more glass bead content, the higher the albedo. This was also observed in the study of Zhang [11], where it was concluded that the higher the density of glass beads, the more light that is retroreflected.

Overall, the addition of powdered *P. placenta* shells increased the reflectivity of the concrete slabs applied with paint. This would mean that the powdered shells acted as good retroreflectors. The powder is also better sprinkled rather than mixed with the paint to prevent it from being covered with pigments and thus, maximizing its effect.

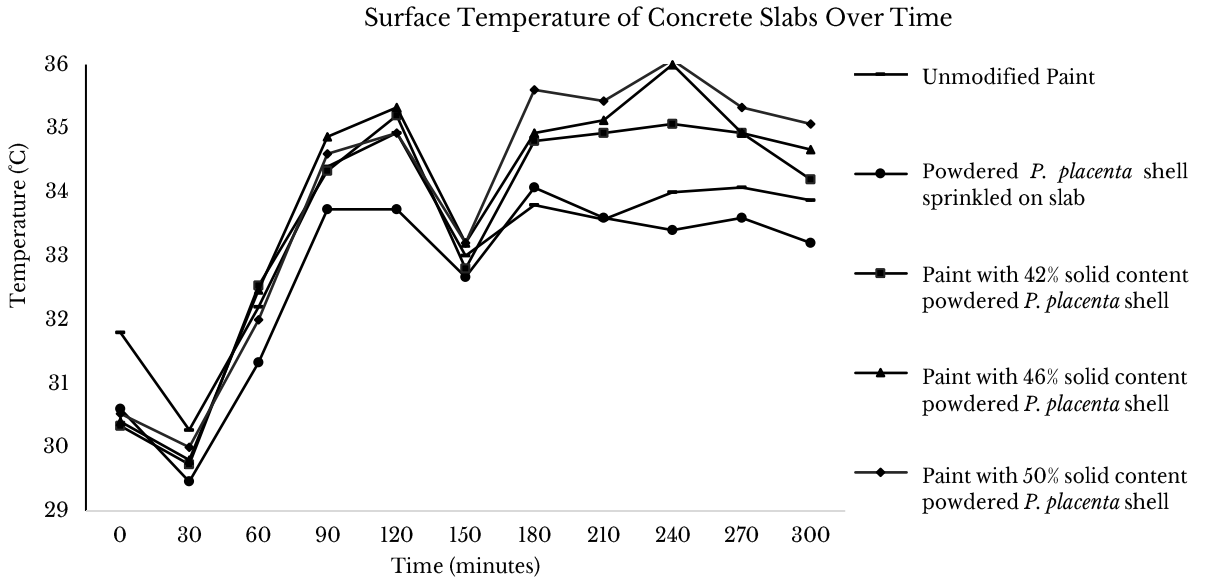

Figure 1. Graph showing the change in surface temperature of concrete slabs over time.

Temperature. Temperature, the degree or intensity of heat present in the concrete slabs, was measured using a Fluke Mini IR Thermometer. The temperatures of all setups followed a descending trend for the first 30 minutes, before ascending for an hour and stabilizing after the 90-min mark. The graphed results are shown in Figure 1 below.

One-way ANOVA was used to determine whether there are significant differences between the surface temperatures of the concrete slabs at different time intervals. The results of six intervals were significant; hence, Tukey post-hoc tests were run to confirm where the significant difference occurred. The values of temperature between the different concrete slabs were statistically insignificant, however, despite the theorized relation between the reflectivity and temperature of the concrete slabs.

The results of the study failed to replicate the success of Chaiyosburana et. al. [6] where their paints with higher reflectivity due to the addition of retroreflectors were able to lower the temperature of the building. In theory, higher reflectivity should have meant lower temperature for the surface but this was not observed in study.

The addition of powdered *P. placenta* shells did not make a significant difference in the temperature of the concrete slabs, despite the expected outcome of the shells lowering the temperature. Externalities such as uneven cloud cover and varying heat transfer like wind convection caused by the outdoor setup are the probable reasons.

Error Analysis. Gross errors and blunders may arise from taking down the data from the thermogun and the Albedo: A Reflectance App™, as well as during the paint tests. To prevent these errors, at least two researchers are cross-examining the data recorded by each other at all times. Measurement errors can also stem from the equipment such as the thermogun, smartphone and analytical scale used. Such equipment were calibrated before each usage to minimize these type of errors.

Systematic errors may happen due to the lack of knowledge on certain areas by the researchers. Paint tests that required specialized instruments needed the guide of a laboratory technician in order to prevent misuse leading to instrumental errors. The method of basking the test cells under the sun is very prone to environmental errors as the area of experimentation is open and factors such as wind, cloud cover and humidity cannot be controlled.

Conclusion. Powdered *P. placenta* shells can be used as a paint additive, as the mixtures passed the standard paint tests of DPWH VI. It effectively increased the surface reflectivity of concrete slabs as shown in the albedo testing. The temperature tests however, did not give any indication that the *P. placenta* shell powder was able to help mitigate the temperature of the surface it was painted on. We can therefore conclude that powdered *P. placenta* shells can be added to paint as retroreflectors in order to increase the percentage of light reflected by the surface.

Recommendations. It is recommended to minimize the risk of externalities by conducting the study in a controlled environment as well as reducing methods with human biases. For more accurate results, it is recommended to have less reliance on natural and environmental phenomena such as solar heat source such the sun as a heat source. Using an indoor setting would ensure that there will be less external factors such as cloud cover and heat convection through the wind that might affect the setups.

Use of a spectrophotometer, instead of reflectance software application, for the measurement of albedo is recommended as it gives the function of reflectivity over wavelength. This may provide another perspective on the effects of adding the powdered shell.

In order to minimize human bias, less methods should be done by hand. This would include using a mechanical sieve shaker for the sprinkling of the powdered shells and an automated paint sprayer. This would reduce the errors that may arrive from the repetition of each method.

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