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The Effect of Natural Stone Grain Size on Indoor Temperature Reduction Through the Coating Process on Galvanised Roofs

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ABSTRACT: The capacity of a roof to absorb heat played a vital role in maintaining indoor temperature stability. Employing composite coatings made from natural materials presented a promising solution for contemporary roofing systems. This study explored the impact of incorporating natural stone powder combined with epoxy as a coating on galvalume roofing, focusing on its effects on thermal conductivity and indoor temperature reduction based on powder sizes. Temperature data were gathered from a small structure featuring a roof treated with the composite coating, which included andesite natural stones. Thermocouples were placed 20 cm above the roof, on the coated surface, beneath the galvalume layer, and inside the room to monitor heat transfer. The findings revealed that adding natural stone powder to roofing materials effectively lowered thermal conductivity and indoor temperature. The degree of temperature reduction varied depending on the size of the stone powder. Ultimately, the study confirmed that the inherent characteristics of natural stone powder size contributed significantly to enhancing a roof's insulation properties and reducing heat buildup indoors.

KEYWORDS: Natural stone; grain size; galvanised roof; thermal insulation; passive cooling; temperature reduction.

1. Introduction

Roofing materials played a crucial role in determining the thermal comfort of buildings, especially in regions with high solar irradiance. Among the commonly used materials, Galvalume—a steel sheet coated with aluminium and zinc—gained popularity due to its corrosion resistance, structural strength, and economic viability. However, its high thermal conductivity also contributed significantly to indoor heat gain, leading to elevated room temperatures and higher energy demands for air conditioning systems [1–6].

One way to reduce the temperature on metal roofs was by applying a coating capable of absorbing heat. When natural stone powder was added as part of this coating, the grain size of the stone affected the material's thermal properties. In addition, the grain size also influenced the thermal resistance of the composite material [7–9].

Natural stone was an ideal choice due to its heat-repellent properties. There were three types of natural stone: marble, travertine, and andesite, each formed through different geological mechanisms, and their thermal conductivity and heat transfer characteristics were studied using infrared thermography. These stones had been utilised as insulating materials for building coatings [10]. Natural stone with low thermal conductivity could enhance insulation in buildings [11, 12]. Adding natural stone hindered direct heat transfer between sunlight and the galvanised roof, helping maintain a cooler indoor temperature. A coating method could add natural stone material to galvanised roofs. The stone was processed to minimise its particle size so it could be mixed with an adhesive medium and then applied to the galvanised surface. The mineral composition and texture of the stone primarily influenced thermal conductivity [13, 14].

A study was conducted on natural stone's thermal insulation capacity and thermal conductivity using an infrared thermography heating method. This research employed three types of local stones as test materials: marble, travertine, and andesite. The results showed a reduction in the surface temperature of each stone, indicating that natural stone could absorb the applied heat, with andesite proving to be the most effective type [10]. Research was conducted on the effect of grain size on thermal resistance and thermal conductivity. The results concluded that the smaller the grain size, the higher the thermal resistance. The thermal conductivity values were lower for smaller grain sizes. Grain size (or particle size) referred to the diameter of individual sediment grains or lithic particles in clastic rocks. This term could also be applied to other granular materials [8]. Heat transfer, or conduction, was described as energy transfer due to adjacent temperature gradients. The amount of heat transferred depended on porosity, shape, temperature intervals, humidity, and uniaxial pressure. The mineral composition and texture of the stone primarily governed thermal conductivity [13].

Metal roofing contributed to elevated indoor temperatures, and reducing the heat in the space beneath it required innovation. Thus, the underutilized potential of natural stone came into focus. Using natural stone composites on galvalume roofs emerged as an alternative capable of providing a solution to the issue of high environmental and indoor temperatures. This raised important questions: How was the thermal conductivity of metal roofing affected by adding composite materials made from natural stone with varying grain sizes? To what extent could this addition reduce the temperature beneath the roof? What phenomena occurred when such a composite effectively lowered the temperature? Furthermore, it was essential to investigate the heat transfer when a composite material containing natural stone grains was applied as a coating on metal roofs.

2. Materials and Methods

This study used a proper experimental approach. It aimed to generate information regarding temperature reduction, thermal conductivity, and macroscopic photographs of the stone coating. The independent variable in this study was the grain size, which varied across three ranges: 0.560–0.630 mm, 0.315–0.355 mm, and 0.05–0.1 mm. The heat transfer process on a roof exposed to sunlight involved the mechanisms of radiation and conduction. Heat flow occurred above and below the roof when the composite roof absorbed solar heat. In the upper part, heat was transferred through radiation and convection, while conduction occurred directly through the roof structure, flowing downward (Figure 1).

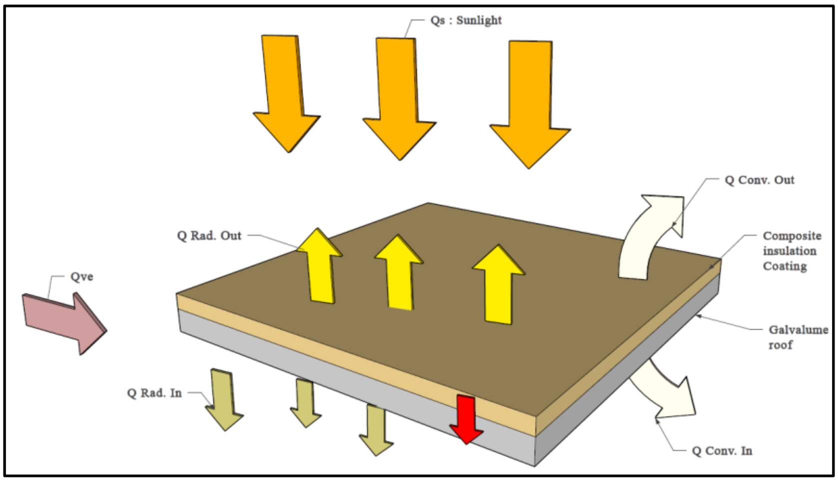


Figure 1. Heat transfer mechanism.

The phenomenon can be expressed in the following equation:

$$Qs = Qrad.out + Qconv.out + Qcond. \qquad (1)$$

Qs represents the amount of solar radiation received, while Qrad.out describes how the roof surface or an object can reflect heat radiation. Qconv.out indicates the heat transfer occurring through convection on the roof, expressed in watts. Meanwhile, Qcond describes the heat flow moving downward through the roofing material by conduction.

Based on this equation, conduction plays a significant role in determining the magnitude of heat flow from the top to the bottom of the roof, which is then distributed throughout the room via convection, as explained in the following equation:

$$Qcond. = Qrad.in + Qconv.in + Qve. \qquad (2)$$

The heat entering the room through radiation is represented as Qrad.in, and its magnitude is measured in watts. Meanwhile, heat transfer by convection is denoted as Qconv.in (W). If there is airflow carrying heat into the room, its contribution is indicated by Qve (W) [16].

The two equations discussed above indicate that the roof's thermal conductivity significantly affects the heat transfer rate into the room below. Therefore, to lower the indoor temperature, it is essential to inhibit conductive heat flow—one way to achieve this is by using roofing materials with low thermal conductivity. By doing so, the amount of heat entering the room can be reduced, resulting in a cooler indoor environment [16].

2.1. Variable of research.

2.1.1. Dependant variable.

The dependent variable is the temperature reduction beneath the coated galvanised roof specimen.

The controlled variables in this study are:
- The heat source, which is sunlight
- The type of rock used is andesite
- The composition ratio of andesite stone to epoxy is 1:1
- The resin used is epoxy resin
- The matrix material used as a binder is epoxy, with a ratio of 50 grams of hardener per 100 grams of resin

2.1.2. Specimen coated.

The specimen coating was prepared using the hand lay-up method. Before coating, a 50 × 50 cm galvanised sheet was fitted with a mould and sealed with sealing tape along the outer edges. The mould's inner surface was coated with a release agent to ensure easy removal of the coating. The resin was mixed with hardener in a 2:1 ratio (100 grams resin to 50 grams hardener). Then, the resin-hardener mixture was combined with andesite stone powder in a 1:1 ratio (50 grams resin-hardener mixture to 50 grams stone powder) using a mixer set at 942 rpm. Although the powders' particle sizes differed, the total weight of the powder-epoxy mixture was kept constant across all specimens to maintain consistent thickness. Consequently, the thickness of all composite coatings was controlled within the range of 2 mm to 2.1 mm. After mixing, the natural stone, resin, and hardener mixture was poured onto the galvanised sheet fitted with the mould and evenly brushed over the entire surface. The specimen was left to dry for approximately six hours before being ready for testing. A miniature box was constructed to measure temperature at three points: above the roof, on the roof, and inside the room (Figure 2).

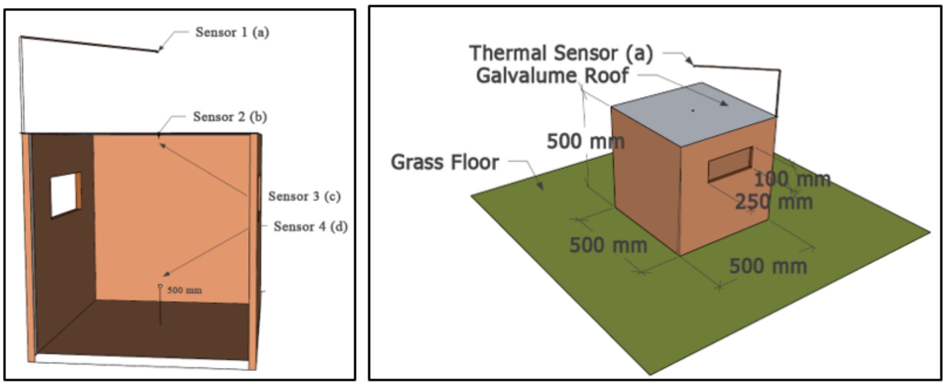


Figure 2. Experiment tools (temperature data mining).

Next, the six miniature boxes were arranged side by side at the exact location, and data collection was carried out simultaneously, ensuring that the heat intensity and environmental conditions during data collection were consistent. For further clarification, refer to Figure 3.

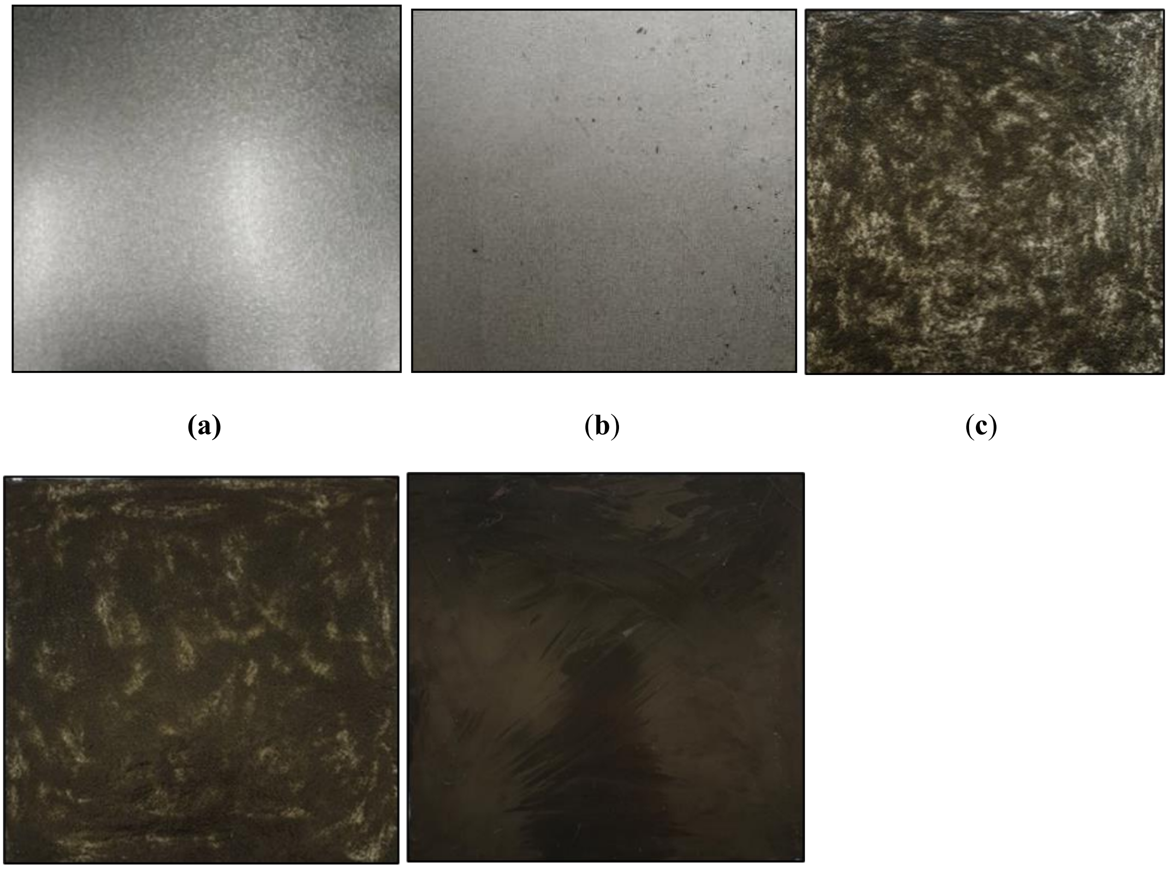
Figure 3. temperature data collection process.

3. Results and Discussion

This study produced several related data points, including macro photographs that can be used to identify the colour and distribution of the powder on the roof, allowing for analysis of how the powder is spread across the surface. In addition, thermal conductivity was measured, indicating the heat transfer rate or the speed at which heat propagates when sunlight hits the constructed roof. Lastly, temperature measurements were taken inside the room and in the environment above the roof and on the roof surface.

3.1 Macroscopic picture analysis of different natural stone types.

The difference in grain size causes a difference in the number of grains, so the smaller the grain size, the greater the possibility for levelling. On the other hand, the larger the grain, the smaller the number, so that many parts look uneven, and the process of covering the surface with natural stone powder becomes less than perfect.



(a) **(b)** **(c)**

(d) **(e)**

Figure 4. Macroscopic pictures of (a) Galvanis; (b) Galvanis coated epoxy; (c) Galvanis coated epoxy and 0.560-0.630 mm andesite stone powder; (d) Galvanis coated epoxy and 0.315-0.355 mm andesite stone powder; (e) Galvanis coated epoxy and 0.05-0.1 mm andesite stone powder.

For galvalume roofs without coating, the metal surface remains exposed and is only covered with clear epoxy (Figure 4). As a result, light that strikes the roof surface comes into direct contact with the metal, significantly influencing the heat absorbed and retained by the roof. The absence of a coating layer on the metal roof allows all incoming light and heat to be fully accommodated. Consequently, the metal's high thermal conductivity causes the surrounding environment to become increasingly hotter.

The image shows that the smaller the grain size, the more evenly the particles are distributed, allowing them to cover the entire surface of the galvanised roof. As a result, the properties of the natural stone powder can effectively inhibit the heat transfer rate to the roof. Additionally, the smaller the grain size, the more vivid the colour appears, indicating that every ray of sunlight hitting the roof will come into contact with the natural stone powder.

3.2 Thermal conductivity analysis of different powder grain sizes.

Andesite stone possesses unique characteristics. In addition to being porous, this type of rock contains a high amount of silica, which can absorb heat due to silicon (Si) being a semiconductor. As a result, materials with high Si content exhibit low thermal conductivity, making them highly suitable for thermal insulation [10]. Thermal protection, energy conservation and thermal insulation materials level depend on thermal conductivity [15]. The differences in grain sizes for heat reduction on the roof also depend on these thermal properties. As Table 1 shows, they proved to be different.

Table 1. Thermal conductivity of different roof types

Roof Type	**Thermal Conductivity (W/m.^{o}C)**
Galvanis	9.39
Galvanised coated epoxy	6.67
0,56-0,63 mm powder	1.842
0,32-0,36mm powder coated	1.278
0.05-0.10mm powder coated	0.766

Three sizes of rock powder were used; compared to a galvanised roof without a coating and with only an epoxy coating, there is a significant difference in the level of thermal conductivity. From these differences, it can be ascertained that the addition of temple stone powder contributed to decreasing the level of thermal conductivity. The smallest powder size, 0.05-0.1mm, decreased the thermal conductivity. This is because the touch surface between the powder and epoxy and galvanising is also getting bigger (Table 2), so the temperature absorption process is also getting more significant.

Table 2. Comparison of contact surface area of powder with different particle sizes

Roof Type	**Diameter Average (mm)**	**Volume (mm^3)**	**Surface area (mm^2)**	**Number of spheres/powder particles in a volume of 2 x 10 x 10 mm^3 (grains)**	**Contact surface area between powder and epoxy (mm^2)**
0,56-0,63 mm powder	1.842	0.1103	11.127	1813	2017.33
0,32-0,36mm powder coated	1.278	0.206	0.3629	9709	3523.40
0.05-0.10mm powder-coated	0.766	0.14137	0.002827	14185307	40101.86

If we relate this to the surface distribution shown in the macroscopic photo above, it can be seen that each grain of natural stone at the smallest size allows heat to pass through evenly and effectively. As a result, the inherent properties of natural stone, which have significantly lower thermal conductivity than metal, can inhibit the rate of conductive heat transfer. The thermal conductivity test results show that the smaller the andesite grain size, the greater its ability to reduce the material's overall thermal conductivity.

3.3 Thermal level analysis of the different sizes of temple stone powders.

The data states that the grain size difference affects the heat absorption rate. In addition to the different levels of thermal conductivity, the effect on the room's temperature is also different. This is evidenced by measuring the miniature box, where the roof is galvanised with a layer of temple stone powder of a different size. The difference causes the temperature in the miniature box room to also vary. For more clarity, Figure 5 shows the differences between the types of roofs, and the resulting temperature levels are visible.

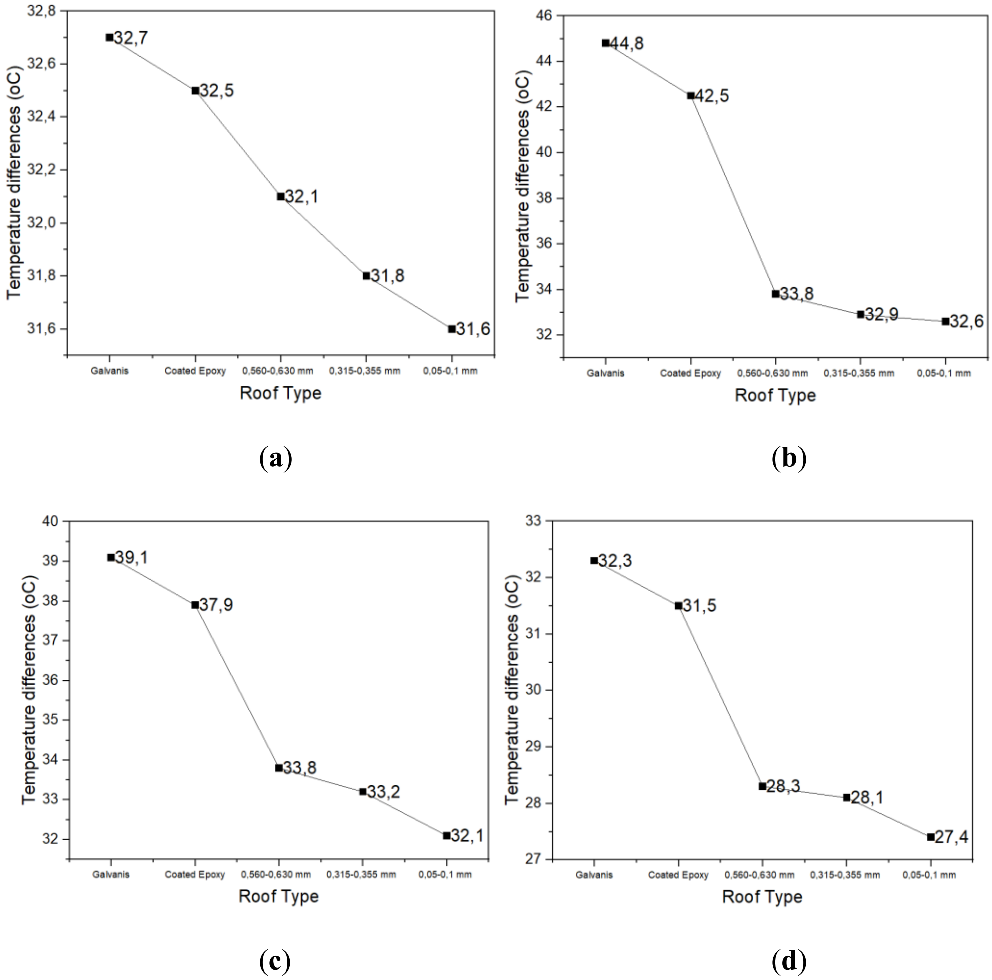


Figure 5 . Roof type and average thermal level; (a) Average Temperature 200mm above roof; (b) Average Temperature above (stick on) roof or composite; (c) Average Temperature under (stick on) galvanis; (d) Average Temperature room temperature - 10 cm heigh from floor – see experiment box.

Figure 5(a) shows the difference in air temperature at a distance of 20 cm above the roof. Figure 5(a) shows how applying a layer of andesite stone powder can lower the air temperature above the roof. The smaller the particle size used, the greater the reduction in air temperature above the roof. The roof coated with a mixture of andesite powder exhibits a slightly lower temperature than the one covered solely with epoxy illustrated in Figure 5(b), factors such as solar heat gain (Qs), radiative heat (Qrad), convective heat loss (Qconv.out), ventilation (Qve), and potentially conductive heat (Qcond) collectively influence temperature changes. The andesite composite material's silicon-rich compounds significantly boost heat absorption. According to Figure 5(c), sensors placed beneath the roof consistently register lower temperatures when a layer of sand powder is present, likely due to the stabilising effect of the natural stone powder.

Figure 5(d) further shows that applying an andesite powder-based composite coating to a galvalume roof results in greater temperature reduction than leaving the roof uncoated. This implies that the topmost composite layer, consisting of various powder sizes, is an effective barrier to heat transfer, reducing thermal conductivity and creating noticeable temperature gradients between the roof's top and bottom layers.

4. Conclusions

This study can provide an overview of the use of composite coatings on galvanised roofs by utilising the fundamental properties of some natural stones that can reduce the level of thermal conductivity of galvanised roofs, after applying a composite layer of a mixture of natural stone powder and epoxy. The strategy of proving that natural stone can reduce room temperature is to make a miniature room with the required amount, so that room temperature measurements can be carried out simultaneously, using a galvanised roof without coating as a reference for temperature reduction. From the data collection and analysis conducted, it was found that:

– The smaller the grain size of andesite natural stone, the more evenly it can be distributed across the metal roof's surface, providing better coverage.
– As the grain size decreases, the thermal conductivity of the composite material also decreases, thereby reducing the heat transfer rate. The smaller the grain size of the andesite stone, the lower the room temperature.
– Thus, it can be concluded that adding andesite stone powder as a coating on metal roofs has been proven to reduce room and ambient temperatures around the metal roof.

The smaller the grain size, the more effective it is in blocking heat from entering the room, lowering the temperature beneath the metal roofing. It was found that the addition of natural stone powder and grain size affects the thermal conductivity of the roofing material, which can be used as a coating on galvanised roofs to decrease room temperature. This research is expected to contribute to readers and further researchers' ability to continue research on using natural stone powder as a medium for reducing the heat of the room temperature below it and reducing energy use for cooling the room in the summer.

Author Contribution

Each author has contributed as follows: Conceptualisation: Redi Bintarto; Methodology: Nurkholis Hamidi; Data Collection: Sugiarto; Data Analysis: Teguh Dwi Widodo; Writing: Redi Bintarto; Rudianto Raharjo; Review: Kamil Gatnar.

Competing Interest

This research was funded personally and through contributions from each member. All researchers worked professionally, and no incidents could interfere with the study's progress.

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