Utilization of Ceramics Sanitaryware Waste (CSW) as an Admixture Material of Cooling Paint Products to Apply in Eco-Friendly Sustainability Infrastructure

Hendra Kustiawan[1], Suwanna Boontanon[2], Sayam Aroonsrimorakot[1], and Narin Boontanon[1]
[1] Faculty of Environment and Resource Studies, Mahidol University, Phuttamonthon Sai 4, Salaya, Phuttamonthon, Nakhon Pathom 73170, Thailand
[2] Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Phuttamonthon Sai 4, Salaya, Phuttamonthon, Nakhon Pathom 73170, Thailand

ARTICLE INFO

Article history:

Received January 10, 2024
Revised February 20, 2024
Published May 15, 2024

Keywords:

Sanitaryware;
Ceramics Sanitaryware Waste;
Cooling Paint;
Climate Change

ABSTRACT

Sanitaryware is a specific type of ceramic product that holds significant importance in the worldwide ceramics industry. On a global scale, the sanitaryware industry's annual production capacity gradually increased from 352.76 to 391.75 million PCs per year in 2019 to 2021. However, around 28.22 to 30.55 million PCs of these become rejected products, wherein it has including non-biodegradable waste. This study aims to examine the potential of ceramics sanitaryware waste as an admixture material in cooling paint products to mitigate the global warming impact and promote environmental sustainability. The techniques employed involve the combination of ceramics sanitaryware waste in diverse compositions embedded into the acrylic paint, subsequent applications were coated into substrates. Furthermore, measurements were carried out encompassing chemical, physical, and performance analysis. The findings of X-ray fluorescence analysis indicate that ceramics sanitaryware waste is predominantly composed of SiO_2 and Al_2O_3 over 90% with Mullite and Quartz as the major compounds in X-ray diffraction. The density and acidity resulted in > 1.1 g/cm^3 and >7. The solar reflectance achieved an average thermal performance of 91.12%, while the thermal emittance achieved a thermal performance of 98.50%. Heat resistance has resulted in a maximum reduce temperature of -8.5ºC indoors and -10.5ºC outdoors. The thermal images have shown that ceramic sanitaryware waste can reflect sunlight average of > 9ºC compared with ambient. Moreover, in terms of efficiency, cooling paint made from ceramics sanitaryware waste could be estimated to yield energy savings between 25.5% to 31.5% and reduce CO_2 emissions around 0.0384 $KgCO_2eq$ /^{0}C. The study revealed that it can be demonstrated that Ceramics Sanitaryware Waste has significant potential as admixture materials in cooling paint as an alternative solution to combat the heat phenomenon in urban areas and lessen the impact of climate change and global warming.

Corresponding Author:
Narin Boontanoon, Faculty of Environment and Resource Studies, Mahidol University, Phuttamonthon Sai 4 Rd, Salaya, Phuttamonthon, Nakhon Pathom 73170, Thailand. Email : narin.boo@mahidol.ac.th

1. INTRODUCTION

Ceramics is a term that refers to inorganic material and non-metallic substances that are generally made from clay or silicate materials wherein these materials are shaped using a specific technique and through a high-temperature combustion process to give those products maturity [1,2]. In addition, The term "ceramics" originates from the Greek word "keramikos," which defines the art of pottery [3,4]. Moreover, Ceramics have been utilized in diverse applications owing to their multitude of exceptional qualities, including elevated mechanical strength and hardness, reduced thermal conductivity, and superior resistance to wear and corrosion [5]. Sanitaryware products are one of the categories of ceramics which are made from inorganic compounds as raw materials such as clays, feldspar, kaolin, quartz, and calcium carbonate then cast into gypsum and dried and fired at a high temperature of around 1200-1250°C [6,7]. Moreover, Sanitaryware refers to the many fixtures and fittings used in bathrooms or restrooms, such as toilets, washbasins, pedestals, bidets, and urinals [8,9].

Generally, the ceramics industry is commonly classified into two overarching areas that encompass conventional ceramics such as tiles, bricks, sanitaryware, and tableware, and advanced ceramics such as bio-ceramics, ceramics electronics and nano ceramics coating [2]. According to Ceramics world Review in 2022, regarding to conventional ceramics industry, annual tiles production capacity is around 18,339 million m^2, sanitaryware products around 3,9 million tons (estimated 390 million pcs) [10,11]. However, in terms of sanitaryware, around 5 % to 8 % of rejected products result from final production in the manufacturer of sanitaryware products [12] especially and the construction sector is accountable for a significant portion, specifically 25%, of global solid waste production, with ceramic waste being the primary contributor to this statistic [13].

In terms of handling ceramic sanitaryware waste (CSW), some manufacturers have tried to carry out a circular economy approach particularly in re-use as raw materials in the production process, nonetheless, less than 5% of that waste can be used as raw material in sanitaryware production itself. Another effort is recycling CSW as an admixture in concrete, ceramic tiles, brick products, catalyst, and cement factories [14–18]. however, due to the less effective and need for cooperation with other participants, most of the waste is dumped into landfills. On the contrary, CSW includes non-biodegradable waste due to the length of decomposition of this waste around 4,000 years, and disposing of that waste will be a significant problem in the environment such as soil problem and groundwater pollution [19].

According to this situation, we need to find another alternative solution in order to manage of CSW become more valuable, more option, and give more beneficial particularly in ceramics industry and all relate stakeholder to support circular economy concept in industry as well as one of mitigation process to reduce climate change impact that already happening now such ass global warming by increasing Emission of CO_2 around the world. Therefore, the focus of this research will emphasize reducing heat temperature in the building for supporting on green building concept that is as radiative cooling materials [20,21].

The purpose of this study is to investigate of utilizing CWS as an admixture in cooling paint products as an eco-friendly sustainability building approach, to reduce heat transfer from outside to inside areas or enhance heat resistance. Owing to CSW content high number of ceramics minerals oxide such as silica and alumina compounds, therefore it can be used as a coating agent and enhance their durability to heat resistance such as cooling paint products [22,23]. In addition, to address the heat island phenomenon and mitigate the air-conditioning load, the application of materials with high solar reflectance, commonly referred to as cooling materials, is employed on building exteriors and road surfaces [24,25].

2. RELATED WORKS

The ceramic sanitaryware industry worldwide produces a significant quantity of solid waste. The recycling of ceramic waste is a vital approach to guarantee their proper disposal. In term of research of the utilization of ceramics CSW, there are several studies in literature dealing with these wastes. The results of the mechanical properties of CSW showed that the variation of ceramic CSW is better than fly ash and can improve strength development well (17). Some researchers have successfully investigated the use of CSW in the recycling process such as in concrete products wherein replaced natural sand and gravel with CSW aggregates and observe after firing 1000°C, the loss of strength was similar to that registered for other types of concrete even some parameter indicate better instead of prior [26]. In cement production, found that CSW can add as raw material with blend 10 to 25% due to pozzolanic activities was feasible [27] .

CSW has a high number in permeability number due to low water absorption below 0.50 % wherein it can enhance mechanical properties if used as mortar or concrete and another advantage of this waste is the high number of SiO_2 which signifies that waste has better pozzolanic reactivity so that can be harness as a binder as well in mortar or concrete product [28]. *L.G Li et al, 2019*, conducted research of ceramics waste, there are two categories of utilizing this waste in case of concrete and mortar products that is a replacement in cement and replacement in aggregate through identifies the replacement of paste in mortar products with change composition of cement, water by adding ceramics waste in certain parts. The result revealed that utilizing ceramics waste as paste can reduce cement content till 33% and enhance compressive strength until 85% [29]. *M.H Roushdy, 2022* try to investigate the feasibility of utilizing CSW gypsum mold wherein high content of Calcium oxide (CaO) as a heterogeneous catalyst in biodiesel synthesis and the result revealed that the biodiesel product from this catalyst has met all requirements of related standards. Nevertheless, its CaO from CSW mold cannot be reuse as catalyst in next process [30].

Based on previous research, it has been proven that CSW can be utilized to become a more valuable product rather than disposed into landfill areas. Nevertheless, the research showed only a few numbers can be utilized as substitution materials. in this research, the author plans to find other alternatives how to utilize CSW to obtain more benefits such as can reduce of natural raw materials as well as reducing global warming effect.

Therefore, in this research, the author tries to investigate the utilization of CSW as an admixture in cooling paint product to reduce heat transfer from outside to inside to keep room more comfortable naturally without increasing energy consumption.

3. METHODS

3.1. Preparation of Coating materials

First of all, the Sanitaryware waste collected from the manufacturer in dry condition is crushed gradually by the hammer to reduce size between 5 cm to 10 cm and subsequently reduced by crushing machine into grain sizes 1 mm to 5 mm). the last step reduces the particles using a milling machine until less than 0.25 mm or passes from size 60 mesh, 120 mesh, 200 mesh, 230 mesh, 270 mesh, and 325 mesh tools. Subsequently, commercial emulsion paint was prepared by the supplier with white color as a based paint as well as commercial cooling paint product as a reference, and the de-mineral water was prepared by the supplier. The last one is the substrate panel or application materials prepared using Aluminum, Glass, Hardboard, or Wood panel following the *ISO 1514 series* [31]**.** Furthermore, every single fine material of CSW was added in the same portion to the commercial acrylic paint with additional Demin water as dilution. Afterward, all samples are homogenous then poured into the container and applied to every substrate.

3.2. Instrument and Characterization

The morphology of the sample CSW was observed by Particle Size Analyzer Horiba Partica Mini Series LA 350. The chemical analysis was performed by XRF Bruker S8 Tiger and XRD Bruker D8 Discover series. Physical Analysis was performed by Pycnometer glass and analytical balance for density and pH meter Mettler Toledo for acidity. The heat resistance was observed by thermocouple digital type K, Manual Data logger temperature and IR lamp for indoor measurement with a simulation box size 21.5 cm x 15.5 cm x 10.5 cm made from polystyrene materials. The solar reflectance was measured by Spectrophotometer UV-VIS-NIR Perkin Elmer brand series Lambda 950 from 2500 nm to 300 nm with an integrated sphere for the sample holder. The thermal emittance was analyzed by FTIR Microscope Thermo-Scientific type Nicolet iN10MX between selected wavelengths from 8 μm to 13 μm. The thermal Images were carried out by Thermal Imager Mileseey brand series TR 256.

3.3. Methodology

Firstly, CSW powder which is distinguished by meshing size passes 0.25 mm, 0.125 mm, 0.074 mm, 0.063 mm, 0.053 mm, and 0.044 mm respectively, in the other hand use 60, 120, 200, 230, 270, and 325 mesh number. Subsequently, all those samples performed chemical analysis using X-ray diffraction, X-ray fluorescence, and Particle Size Analyzer measurements following each method in that instrument.

Secondly, in different parts, every single fine particle weighed around a 15% weight ratio and mixed with the acrylic paint by adding demineralized water as a diluter as around a 10% weight ratio. Furthermore, all samples were stirred using a mixer until homogenous. Afterward, the vacuum chambers were used to minimize the bubble in the sample solution around. For commercial cooling paint made by change of acrylic paint to commercial cooling paint. Subsequently, all samples were conducted performance test encompasses acidity test, density test, heat resistance test, solar reflectance test, thermal emittance test, and thermal images test respectively. Moreover, in terms of performance test such as heat resistances and thermal images was used different substrate including Aluminum, Glass, and Hardboard. Finally, the result of heat resistance was estimated to measure the energy saving of cooling paint in reduction of electricity usage as well as estimated its reduction of CO_2 emission.

4. RESULTS AND DISCUSSION

4.1. Chemical Analysis

4.1.1. Particle Size Analysis

Particle size analysis is a technical method used to precisely determine the distribution of particle sizes in many phases of a system including powder, aerosol, suspension and many others in liquid [32]. The principle of this analysis is material distributed in a liquid or gas and passed through a monochromatic light source (laser) wherein multi-element detectors measure the scattered light from particles at different angles and store numerical data for analysis [33]. Furthermore, using an optical model and mathematical technique, the numerical scattering data are translated into a volumetric particle size distribution (PSD), which represents the proportion of the total volume of particles to discrete size classes (ISO 13320:2009) [32]. In this research, particle size analysis was conducted by using Laser diffraction method to evaluate the uniformity of particles based on their size [34]. This method applicable from 0.1 – 1000 um and according to ISO 13320: 2009. The result shown in Figure 1 as follow:

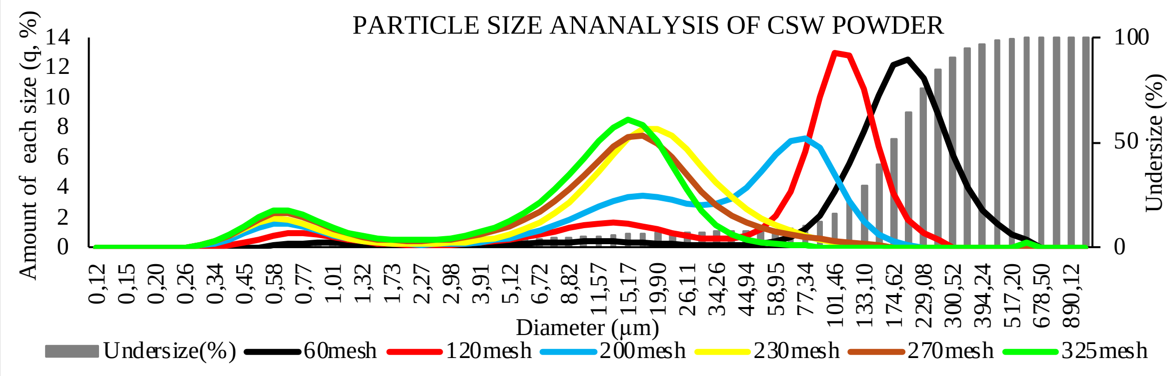


Fig. 1. Particle size distribution of CSW in certain sieve measurement

According to Table 1, the value of diameter on distribution particle size is indicated by mean number, not by median. The mean value is similar to the concept of average while the median just shows the middle point of the data [35]. Nevertheless, it is crucial to thoroughly assess the essential factors related to laser diffraction particle size analysis, including dispersant, stirring rate, refractive index, and absorption index [34]. In addition, it shows that PSA analysis can be more accurate in showing the number of size particles than sieve measurement, for example in sieve measurement with 200 mesh was indicated that the particle distribution will be lower than 75 microns whereas in PSA analysis result can be mentioned that the particle size of CSW 200 mesh was 43.87 microns.

Table 1. Result of Measurement Distribution of Particle size of CSW

No	CSW size	Mode (µm)	Median (µm)	Mean (µm)
1	60 mesh	186.25	171.96	180.82
2	120 mesh	103.67	89.00	82.32
3	200 mesh	71.93	37.27	43.87
4	230 mesh	18.53	15.84	19.32
5	270 mesh	16.17	12.78	16.51
6	325 mesh	14.19	11.16	16.08

4.1.2 X-ray Diffraction (XRD)

X-ray diffraction (XRD) is a non-destructive method used to analyze a diverse range of materials like phase composition, structure, texture, and many more of powder samples, solid or even liquid samples [36]. XRD is commonly used for the determination of crystal structures. Identification of phases and unknown substances [37]. Moreover, X-ray diffraction has become a prevalent method for investigating crystal structures and the distances between atoms by comparing an unknown result of the X-ray diffraction pattern with its reference in the database [38] . X-ray diffraction relies on the phenomenon of constructive interference between monochromatic X-rays and a crystalline sample [39].

In this research, the sample prepared by different particle sizes commence by 60, 120, 200, 230, 270, and 325 mesh, respectively from 10 degree to 90 degrees of theta continuously. The result shows as follow :

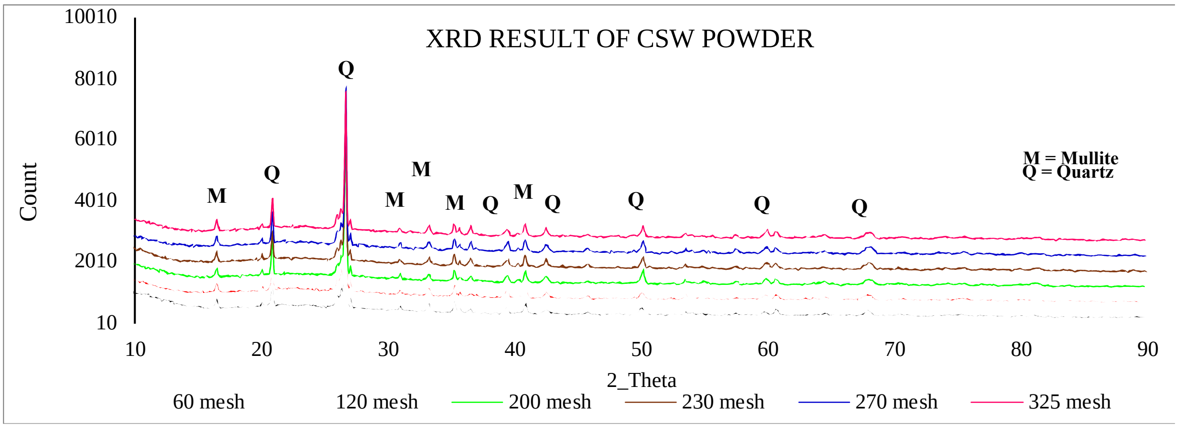


Fig. 2. XRD result of CSW samples in different particle sizes

In Figure 2 depicts of diffractogram or pattern phase of CSW samples from 10 to 90 degree in 2theta and the result show that after comparing with the database of pattern, these peaks of pattern have similarity with a peak of Mullite mineral with pattern PDF-01-0769282 and Quartz Mineral with pattern PDF 01-089-2814.The content of Mineral Mullite and Quartz in Sanitaryware waste in this result same as the previous research related to CSW such as *T.H Silva et al, 2019* revealed that the biggest content of CSW in minerals is Mullite and Quartz. *M.H Rousdy, 2019* has proved that the mineralogy of Sanitaryware waste is mostly composed of Quartz and Mullite added with other compounds such as Calcite ($CaCO_3$), Albite ($AlSi_3O_8$) and Ortho class K ($Al.FeSi_2O_8$) [15,40].

4.1.3 X-ray Fluorescence (XRF)

X-ray fluorescence (XRF) is an analytical technique used to ascertain the chemical composition of various materials in wide range of samples including solids, powders, liquids, filtered substances, and other forms [41,42]. Generally, this method were quick, good in precision, and non-destructive to the samples including cement, metals, oil, polymer, plastic, food industry, and waste materials as well as could be used to analyze of thickness and content of coating and layer [43]. Generally, XRF analysis is divided into two main classes namely Energy Disperse system X-ray (EDX) and Wavelength Disperse system X-ray (WDXRF) either in qualitative or quantitative measurement [42] .

In this research, XRF were used is WDXRF to CSW sample representative with particle size 200, 270, and 325 mesh, respectively. The results show in Table 2 as follows:

Table 2. Chemical Composition of Ceramics Sanitaryware Waste

Sample size	SiO_2	Al_2O_3	K_2O	Na_2O	Fe_2O_3	CaO	MgO	TiO_2	ZnO	Total
200 mesh	67.50	23.20	2.67	2.44	1.46	1.47	0.66	0.34	0.30	100
270 mesh	67.50	23.20	2.83	2.35	1.60	1.34	0.62	0.34	0.27	100
325 mesh	67.20	23.40	2.95	2.23	1.65	1.34	0.62	0.36	0.25	100

Based on Table 2, it can be seen that the major component or oxide in whole the CSW samples consist of Silica Oxide and Alumina Oxide around 90.6 to 90.7 %. Those oxides appear owing to mostly raw materials of Sanitary ware products come from clays, feldspar, quartz, and kaolin wherein these compounds consist of high contents of silica and alumina oxide from nature [8]. Moreover, the XRF result of CSW has been done by other researcher in ceramics and that result indicated similarity even conduct in different samples. For example *B.Tarhan et al. 2017* revealed that XRF analysis for CSW majority consist of SiO_2 68.59% and Al_2O_3 21.96% [44]. *I.I. Attabey et al. 2022* revealed that CSW consist of major oxide SiO_2 66.32% and Al_2O_3 27.86% [23]. Moreover, *T.H Silva et al. 2019* done testing Sanitaryware waste using XRF and revealed that SiO_2 is 64.53% and Al_2O_3 21.47% [40]. Therefore, based on the research almost all show that the silica and alumina oxide on CSW has more than 85%.

4.2 Physical Analysis

4.2.1 Acidity

In organic chemistry particularly, there are many reactions related the acidity and basicity. The term of Acidity based on Bronsted theory defined as the ability of the compound to donate the proton or proton donor whereas the Basicity is ability of the compound to accept the proton or proton acceptor [45,46]. In addition, another theory from Lewis said that Acid is the ability of a compound to accept an electron pair and Base is the ability of the compound to release an electron pair [47].

In this research, the measuring acidity and basicity was conducted by pH Meter digital from Mettler Toledo brand, the result is show in Figure 3 as follows:

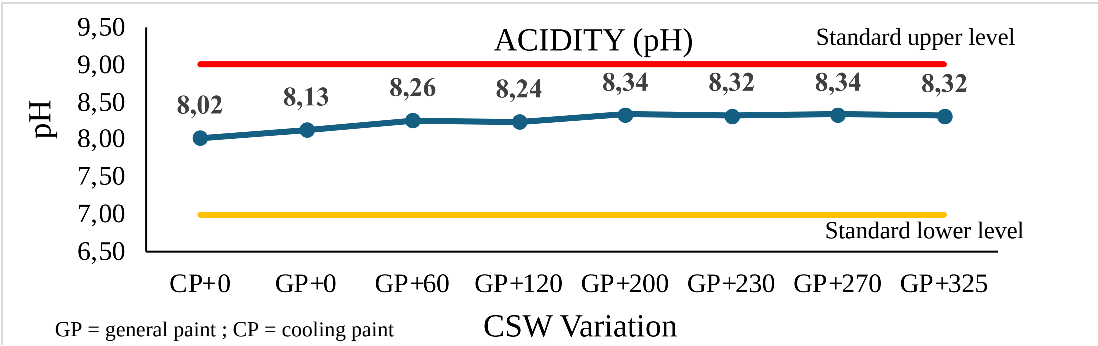


Fig. 3. Acidity of CSW samples in different particle sizes

Based on Figure 3, increasing the particle size of CSW will gradually increase the value of acidity. However, the value of acidity remains in the range of standard pH of Paint products between 7 to 9 according to paint and varnish standards regulation since the alumina and silica oxide effect is tend to balance of pH value between 6.8 – 7.8 and 4 – 9 respectively [48].

4.2.2 Density

According to the American Society for Testing Materials (ASTM) D-1475 Density of material such as paint product is the mass or weight in vacuo of unit volume of liquid at any given temperature (gram per cubic centimeter) [49]. Subsequently, ISO 2811: 2016 also defines the same terminology of Density in Paint or varnish products namely the mass of those products in grams divided by the volume of a portion of materials in cubic centimeters. Both of those standards use the pycnometer method in terms of measurements [50].

In this research, the density was conducted by using the pycnometer method, especially in glass pycnometer and analytical balance with a precision of 0.1 mg for all variations of sample. The result can be shown in Figure 4 as follows:

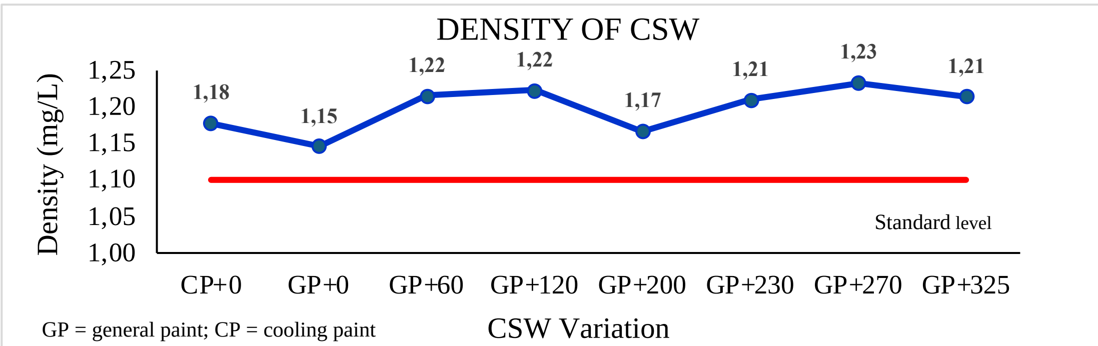


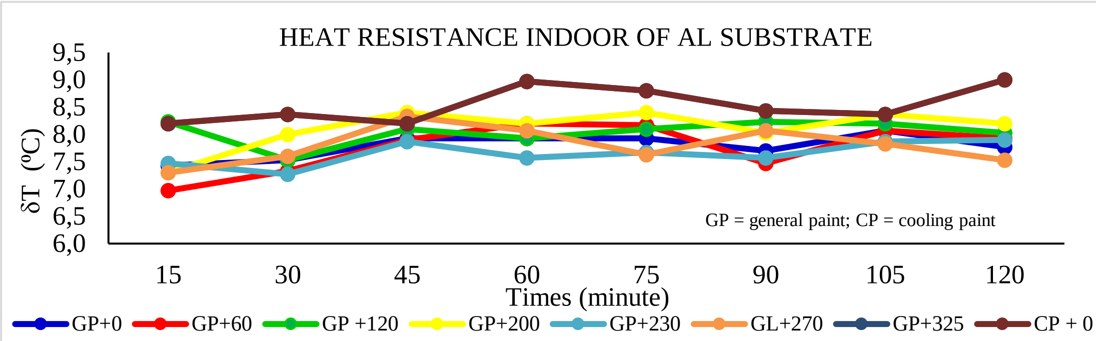
Fig. 4. Density of CSW samples in different particle sizes

Based on Figure 4, the density value of all CSW samples was above the standard value (gathered both from the national standard of Indonesia or SNI and the product standard itself) is more than 1.1 g/cm^3. This means that the density of CSW was acceptable if applied in the paint product due to there is not mentioned the upper level of density in the paint. Moreover, it can be illustrated that the more CSW, the more density increases

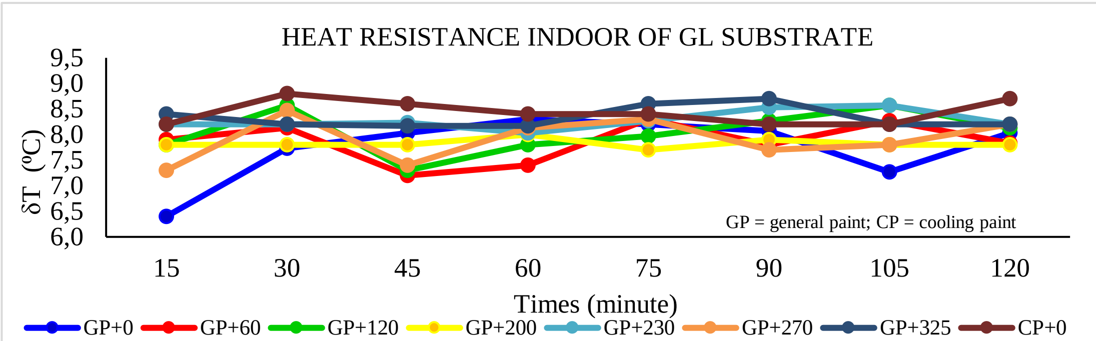
4.3 Performance Analysis

4.3.1 Heat Resistance Test

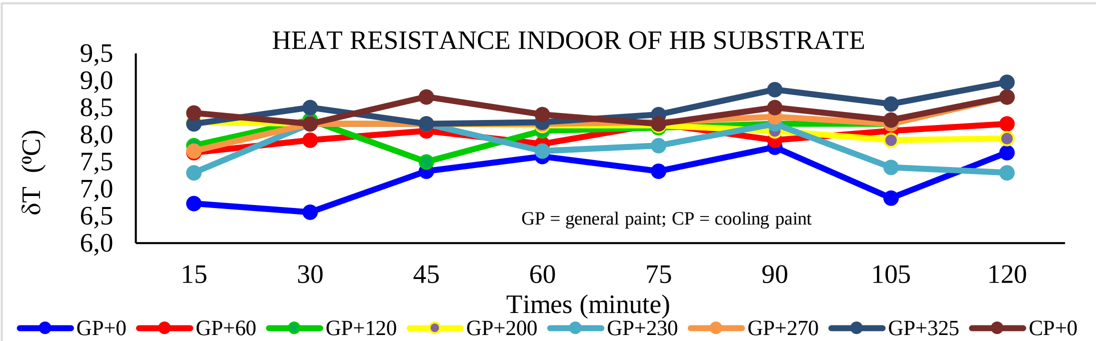
Heat resistance refers to the material or substrate that can be able to maintain its properties both physical and mechanical at a certain time [51]. In addition, Thermal resistance is a measure of the level of difficulty in conducting heat. Thermal resistance is defined as the ratio of the temperature difference between two specific points to the heat flow between those points (the quantity of heat transferred per unit time). This implies that when the thermal resistance increases, the conductivity of heat becomes more challenging, and conversely [52]. Heat resistance of cooling paint materials in this research were investigated under two conditions measurement that is indoor and outdoor experiments wherein in terms of indoor areas, the light source was simulated by the infrared lamp with a dimmer which allowed for control of the intensity of the light close to the real conditions. The result of indoor experiment shows in Figure 5 as follow:



(a)



(b)

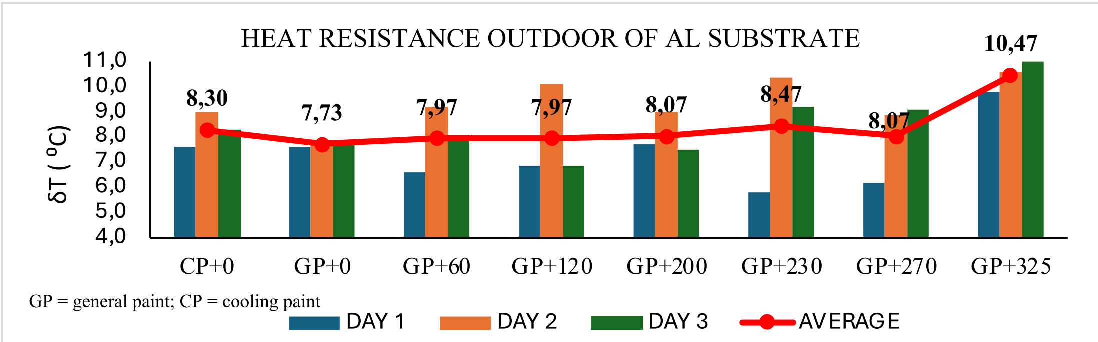


(c)

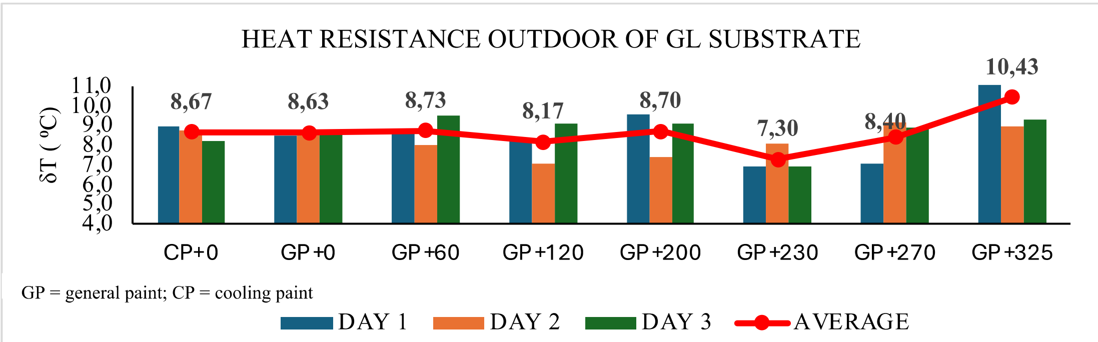
Fig. 5 Heat resistance of Indoor experiment (a) aluminum substrate, (b) glass substrate, and (c) hardboard substrate

According to Figure 5, every single variation of the substrate had given different value of the heat resistance, however, in general, increasing fine particles of CSW materials in cooling paint could gradually rising the ability to reflect heat from outside to inside owing to high content of Silica oxide in CSW wherein this oxide has been discovered to exhibit a high level of infrared emissivity and can serve as durable cooling materials [53]. In terms of the substrate materials, Aluminum selected due to possess high reflectivity material, glass substrate in the middle value of reflectance and hardboard possesses low of reflectivity. The result shown that variation of substrate has no significant effect to the value of heat resistance in indoor condition. Moreover, the highest value on heat resistances such as in Aluminum substrate and Glass substrates, CP+0 is the highest with can reduce as amount 8.5ºC and 8.4ºC respectively, whereas Hardboard substrates have the best value with 8.5ºC on GP 325.

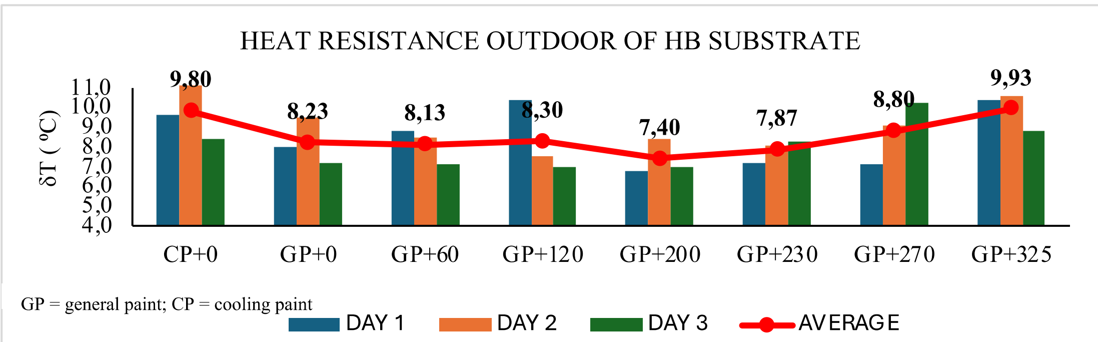
Subsequently, in terms of measurement of heat resistance in outdoor conditions, the sample lies in the rooftop of Building 1 Faculty of Environment and Resources studies Mahidol University, Thailand with latitude 13º47'41" N, longitude 100º19'19"E in vertical direction to simulate a wall in the building from 9.00 am to 3.00 pm with the sun radiation as the source of light during December 2023. The thermocouple type K with temperature logger was used inside the polystyrene box to measure the temperature inside of the wall. Each variation of samples were test divided based on increasing fine particles of CSW. The result shows in the Figure 6 as follow:



(a)



(b)



(c)

Fig. 6. Heat resistance of outdoor experiment (a) aluminum substrate, (b) glass substrate, (c) hardboard substrate

Figure 6(a) to 6(c) shown that in terms of increasing fine particles, there were variations in the number of heat resistance between ambient temperature and inside the sample simulation wherein it shown that increasing fines particle will enhance reflectivity in cooling materials due to its better in scattering in the light [54]. In addition, the heat resistance outdoor were higher than indoor condition owing to the ambient temperature in outdoor direct to heat by sunlight. Moreover, heat resistance in outdoor has discrepancy within each sample owing to some factor uncontrollable such as number of solar radiations high of wind speed and cloud shadow which is different from each day. However, based on the experiments, the highest value of heat resistance in outdoor conditions was in the same variations i.e. GP 325 on all substrates with average values of 10.5ºC, 10.4ºC, and 9.9ºC on Aluminum, Glass, and Hardboard substrates respectively.

4.3.2 Solar Reflectance Test

Solar reflectance, also known as albedo refers to the proportion of sunlight that is directly reflected back into atmosphere from the materials surface or clouds [55]. In addition, a higher score of solar reflectance indicates a greater ability of the roof to reflect solar energy [56]. The measurement of solar reflectance were conducted with wavelength from 300 nm to 2,500 nm on glass substrates to represent other substrates following ISO 9050 series [57]. The result shown in Figure 7 as follows:

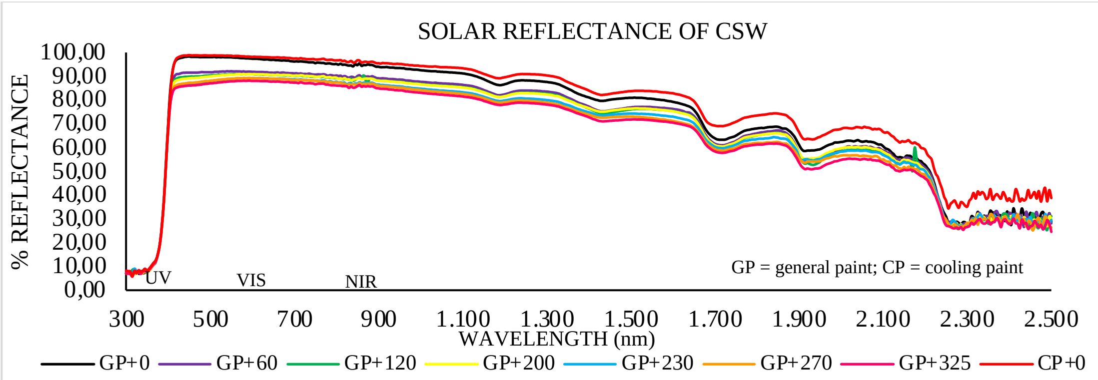


Fig. 7. Solar Reflectance of CSW Variation of fine particle

Based on Figure 7 it can be seen that the solar radiation spectrum generally divided into three zone of wavelength encompass UV wavelength (250 – 380 nm),Visible wavelength (380 – 760 nm), and Near Infrared wavelength (760 – 2,500 nm) [20]. Moreover, the value of reflectivity gradually decreases by increasing fines particles of CSW. It occurring owing to the brightness of sample were gradually reduce from clear white (in GP+0 and CP+0) to slightly grey white in GP+60 to GP+325. In the other hand it indicates that the tint strength of white color in the cooling paint decreases by increasing CSW. Hence, the increment of CSW will affect decreasing the value of solar reflectance due to CSW have grey color in powder. It can considers to combine other materials which is has high number of reflectivity owing to the color of radiative paint has exerts a more significant influence on the optical reflection [58]. However, all the values solar reflectance in this cooling paint remain above the standard Solar reflectance value i.e. more than 80% [59].

4.3.3 Thermal Emittance Test

Thermal emittance also known as thermal emissivity is a terms that refer to the ratio of thermal radiation in certain materials that can be emitted into the environment or atmosphere [60]. In addition, *A.L. Pisello et al 2015* said that thermal emittance is defined as the ability of a surface to radiate absorbed heat back into the environment in the same temperature and bandwidth [61,62]. This property is quantified by a numerical value ranging from 0 to 1 which illustrates the relative emittance in comparison to a blackbody.

In this experiment, thermal emittance was gathered through measurement FTIR Microscope Spectrometer with the sample Aluminum plate as background and wavelength range selected between 8,000 to 13,000 nm following internal method of the instrument with Aluminum plate as a background and Aluminum substrate as a base coating. The result shown in Figure 8 as follows:

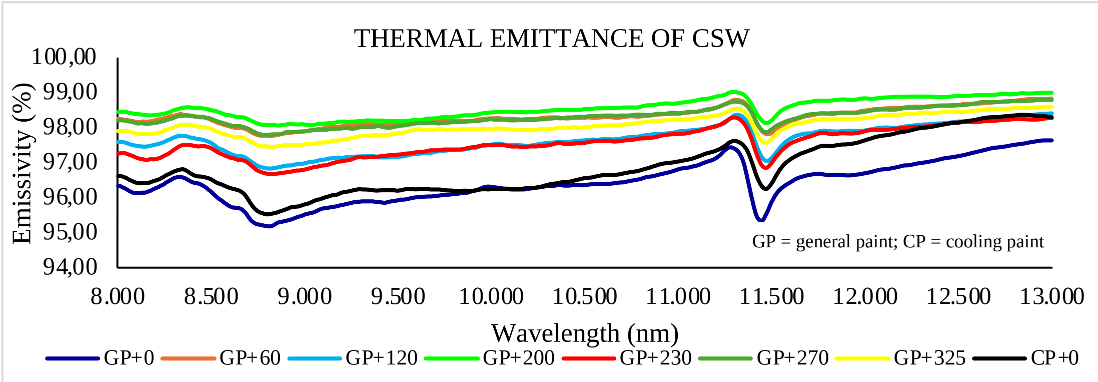
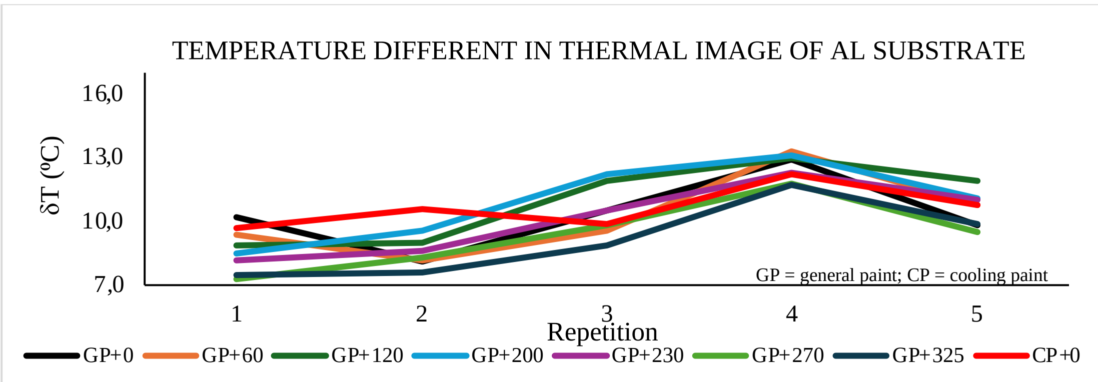


Fig. 8. Thermal Emittance or Emissivity of CSW in Increasing Fine Particles

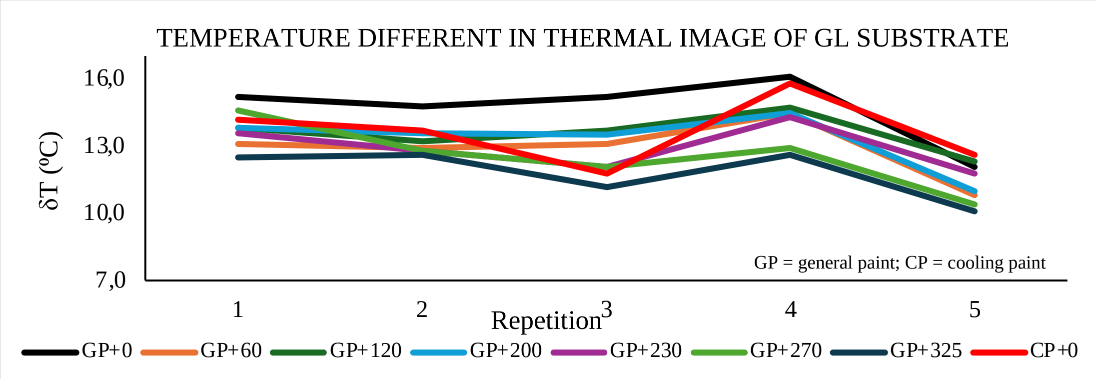
According to Figure 8. above it can be seen that increasing the fine particle of CSW to Cooling paint has increase the value of thermal emittance compared with no addition (GP+0 and CP+0). It's because the Silica content in CSW has improved emissivity of cooling paint. Moreover, *B.Ma et al ,2023* said on his research that particles composed of silica (SiO_2) exhibit a significant inherent ability to emit radiation within the wavelength range of 8–13 um, which aligns with the atmospheric transparent window (ATW) [53]. Hence, It also means that effect of CSW in cooling paint could enhance the ability of absorption of cooling paint to emit the heat from inside to the atmosphere. Furthermore, based on this research, the highest value of average number of increment fine particles occurs in GP 200 with a value of 98.50%.

4.3.4 Thermal Images Test

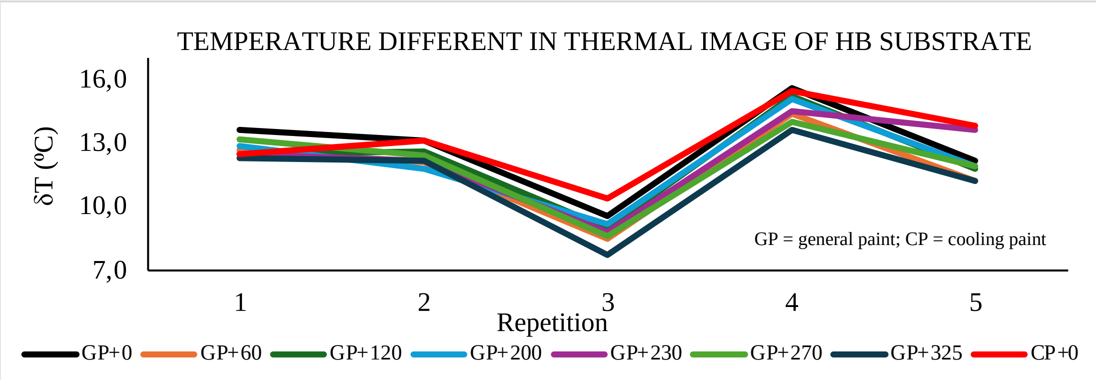
Thermal image also known as thermography is a method in which a thermal camera captures and produces an image by detecting and utilizing infrared radiation emitted by an object [63]. Thermal imaging has been employed over the past five decades as a non-intrusive, contactless, and replicable method for evaluating the temperature distribution of objects with temperatures above absolute zero [64]. The thermal images produced offer a visual representation of the building's structure, the surrounding surroundings, and other components of the construction. Additionally, they can also display the surface temperatures at specific locations [65]. In this research, thermal images were conducted in day time in the rooftop of Building 1 Faculty of Environment and Resource Studies, Mahidol university, Thailand. The result of the measurement of thermal images is shown in Figure 9 as follows:



(a)



(b)



(c)

Fig. 9. Discrepancy of thermal image surface (a) aluminum substrate, (b) glass substrate, (c) hardboard substrate

According to Figure 9, it can be seen that there are experiencing temperature differences for surface temperature of each sample to the ambient temperature around the samples. This variation occurred owing to some factor which uncontrollable during the outdoor measurement including cloudy cover the sun radiation, wind speed variation, and the solar angle to each sample. Moreover, this result along with solar reflectivity measurement wherein addition of CSW gradually reduce the reflectance number in visible and near infrared band. Furthermore, it can be depicted that among of substrate, the glass substrate has highest temperature than other its indicates that glass was better as adsorption material instead of aluminum and hardboard. Subsequenlty, the surface temperature shown that highest temperature difference was 10.9ºC on GP+120 in aluminum substrate whereas glass and hardboard substrates were 14.7ºC and 13.1ºC on GP+0 and CP+0 respectively.

4.4 Energy saving and reduction of CO_2 emission

Radiative cooling (RC) material is an energy-efficient and environmentally friendly material that has gained significant interest in recent years owing to it can prevent heat absorption by reflecting sunlight in the range of 0.3 to 2.5 μm. Additionally, it may emit its heat to the cold outer space through the atmosphere transparent window (ATW) which operates in the range of 8 μm -13 μm, all without requiring any energy expenditure [66]. In accordance with a simulation of energy usage in a standard office building equipped with central air-conditioning, it has been determined that for every 1ºC increase in temperature setting, there is a corresponding decrease of around 3% in electricity consumption by the air-conditioning system [67]. In addition, *Thomas Lawrence* from *University of Georgia* (UGA) research also said that every single degree (1ºC) adjustment in a thermostat setting corresponds to around a 3% rise in energy conservation when compared to typical settings [68] . Moreover, *S.Guo et al, 2019* said that decreasing 10C of temperature air conditioner has generated variation of energy saving in different cities, such as in Hotter city of China was reached as around 11.5% per years and 41.1% in cold city [69]. Therefore, it can be calculated if assumed reduction 1º has 3 % energy saving, hence, the energy saving of eco-cooling paint from SWP when reduction temperature reaches 8.50C and 9.90C are between 25.5% to 29.7% respectively.

In terms of reduction of CO_2 emission, as aforementioned previously, significant energy use necessitates the conversion of a substantial quantity of fossil fuels into electricity, resulting in the release of greenhouse gases, particularly CO_2, which will accelerate global warming. Consequently, the majority of nations have adopted diverse strategies and policies to decrease the consumption of energy in buildings and the release of carbon emissions. For example, in Thailand in 2018, electricity consumption in household reach 35,624 GWh wherein air conditioner demand as reach 9,440 GWh or 26.50 %. In other words, the CO_2 emission has reached 4.53 $MtCO_2$ with emission factor 0.48 tCO_2/MWh [70]. In addition, according to research from Metropolitan Electricity of Authority of Thailand (MEA) Thailand in 2021, it revealed that every single degree Celsius of reduction temperature if Air Conditioning, the consumption of electricity about 0.08KWh [71]. Therefore, it can be calculated based on energy saving electricity that reduction CO_2 emission for every single degree is 0.0384 $kgCO_{2\,eq}$ or if reduction temperature in this result obtained -8.5^{0}C to -10.5^{0}C then, the reduction of CO_2 emission around 0.3264 to 0.4032 $kgCO_{2\,eq}$ / KWh.

5. CONCLUSION

In this research, the eco-cooling paint product was investigated by adding CSW as an admixture material in different fine particle sizes of CSW and apply the coating into three kinds of substrate including Aluminum, Glass, and Hardboard panel by paint brush, roller brush, and scrapper tools until obtained the same thickness on each panel around ± 0.5 mm. The chemical analysis, physical analysis, and performance analysis can be concluded that chemical analysis shown that XRF analysis indicates that CSW has a high number of Alumina and Silica Oxide wherein those compounds have good potential use as heat resistant material in ceramics products, XRD analysis shows that the CSW mostly consists of quartz and Mullite compounds. In terms of PSA analysis indicates that the shape of CSW more accurate number instead on use of mesh tools. The physical Analysis shows that the density of Variation CSW increases gradually compared with the commercial one and owing to the effect of density in CSW. In terms of acidity, the effect of CSW in Cooling paint will increase the pH number gradually with an enhancement of fine particles. Subsequenlty, performance analysis revealed that the heat resistance in both indoor scenario and outdoor scenarios resulted that generally CSW can elevate the value of temperature resistant performance compared with the commercial acrylic paint. As well as the effect of the heat test indicated that incorporating CSW as Cooling paint can increase endurance in extreme weather. Furthermore, the optical test results that in terms of Solar Reflectance, adding CSW will decrease the Solar Reflectance due to this variation giving the effect of slight discoloration from white to yellowish-white. However, in general, the Solar Reflectance of this coating remains > 85% in Visible and > 63% in the NIR band. The thermal emittance indicates that incorporating CSW could elevate the emissivity value > 97% in the atmosphere window spectrum. In addition, regarding thermal image analysis, variation CSW as cooling paint indicates high reflection to the solar compared with the ambient surface.

Based on this research, utilizing CSW as an admixture in cooling paint has proved that the result shows that heat resistance value is different around 8.5 ^{0}C in the indoor experiment and 10.5 ^{0}C in the outdoor experiment with the ambient temperature. Therefore, it can be calculated that the maximum energy saving of eco-cooling paint is estimated when energy saving reach 3% per degree are around 25.50% to 31.50%. In terms reduction of CO_2 Emission, based on the data aforementioned that the potential of CSW as eco cooling paint to obtain energy saving estimated as around 25.50% to 31.50% from total energy consumption amount 9,440 GWh and release the CO_2 emission 4.53 $MtCO_2$. Hence, it can be calculated that incorporating CSW in eco-cooling paint could reduce CO_2 emission as round 1.16 $MtCO_2$ to 1.43 $MtCO_2$ per year with emission factor 0.48 tCO_2/MWh.

Overall, this research has provided a new approach for utilizing CSW as an admixture material in cooling paint products to enhance the effectiveness of commercial acrylic paint, transforming it into eco-friendly cooling paint. The results are encouraging and show potential for commercialization and widespread use.

ACKNOWLEDGMENTS

The Author gratefully acknowledges Mahidol University Frontier Research Facilities (MU-FRF) for using XRD, XRF, PSA, and FT-IR analysis, Laboratory of Faculty Environment and Resource Studies Mahidol University, Laboratory of Enovation Faculty Environment and Resource Studies Mahidol University, and Laboratory testing of Central for Ceramics Bandung. This research was supported by Thailand International Cooperation Agency (TICA) and the Faculty of Environment and Resource Studies, Mahidol University.

REFERENCES

[1] Xiao P. “Frontiers in ceramics” grand challenges. Front Ceram 2023;1:1–2. https://doi.org/10.3389/fceic.2023.1137377.

[2] Furszyfer Del Rio DD, Sovacool BK, Foley AM, Griffiths S, Bazilian M, Kim J, et al. Decarbonizing the ceramics industry: A systematic and critical review of policy options, developments and sociotechnical systems. Renew Sustain Energy Rev 2022;157:112081. https://doi.org/10.1016/j.rser.2022.112081.

[3] Fantozzi G. Welcome to ceramics: A new open access scientific journal on ceramics science and engineering. Ceramics 2018;1:1–2. https://doi.org/10.3390/ceramics1010001.

[4] Mukherjee S. Traditional and Modern Uses of Ceramics, Glass and Refractories. Sci Clays 2013:123–50. https://doi.org/10.1007/978-94-007-6683-9_8.

[5] Grossin D, Monton A, Navarrete-segado P, Ozmen E, Urruth G, Maury F, et al. OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible This is a Publisher ' s version published in : http://oatao.univ-toulouse.fr/27601 Official URL : https://doi.org/1. Open Ceram 2021.

[6] Kunduraci N, Tarhan B, Cahide S. Evaluation of Production Costs Based on Reduction of Pyroplastic Deformation in Ceramic Sanitaryware Products Seramik Sağlık Gereçleri Ürünlerinde Piroplastik Deformasyonun Azaltılmasına Bağlı Olarak Geliştirilen Kompozisyonların Üretim Maliyeti Açısından 2019.

[7] Tarhan B, Tarhan M. Utilization of perlite as an alternative raw material in the production of ceramic sanitaryware. J Therm Anal Calorim 2022;147:3509–18. https://doi.org/10.1007/s10973-021-10784-5.

[8] Silvestry L, Forcina A, Silvestry C, Loppolo G. Life Cycle Assessment of electricity production from refuse derived fuel: A case study in Italy. Sci Total Environ 2020;738. https://doi.org/10.1016/j.scitotenv.2020.139719.

[9] BOYRAZ T, ÖNEN U, TAPİK Ş. Investigation Of The Effect Of Vermiculite (Yıldızeli/Sivas) Addition On The Properties Of Sanitaryware Ceramic. Osmaniye Korkut Ata Üniversitesi Fen Bilim Enstitüsü Derg 2022;5:632–42. https://doi.org/10.47495/okufbed.1050392.

[10] Luca Baraldi. World Production and consumption of sanitaryware. vol. 149. November/D. 2022.

[11] Luca Baraldi. World production and consumption of ceramic tiles. Ceram World Rev 148 2022;148:41–50.

[12] Medina C, Sánchez De Rojas MI, Frías M. Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. Cem Concr Compos 2012;34:48–54. https://doi.org/10.1016/j.cemconcomp.2011.08.015.

[13] Sangwan KS, Choudhary K, Agarwal S. Development of an electric-load intelligence system for component level disaggregation to improve energy efficiency of machine tools. 2020. https://doi.org/10.1007/978-3-030-44248-4_12.

[14] Meena RV, Jain JK, Chouhan HS, Beniwal AS. Use of waste ceramics to produce sustainable concrete: A review. Clean Mater 2022;4. https://doi.org/10.1016/j.clema.2022.100085.

[15] Roushdy MH. Recycling of the mixture resulted from sanitary ware waste, roller kiln waste and ceramic tiles sludge waste in the manufacturing of ceramic floor tiles. Int J Innov Technol Explor Eng 2019;8:379–86. https://doi.org/10.35940/ijitee.K1360.0981119.

[16] Sawadogo M, Seynou M, Zerbo L, Sorgho B, Laure Lecomte-Nana G, Blanchart P, et al. Formulation of Clay Refractory Bricks: Influence of the Nature of Chamotte and the Alumina Content in the Clay. Adv Mater 2020;9:59. https://doi.org/10.11648/j.am.20200904.11.

[17] Bayer Öztürk Z, Atabey İİ. Mechanical and microstructural characteristics of geopolymer mortars at high temperatures produced with ceramic sanitaryware waste. Ceram Int 2022;48:12932–44. https://doi.org/10.1016/j.ceramint.2022.01.166.

[18] Mostari MS, Haque MJ. Recycling of Post Sintered Sanitaryware Waste in Its Formulation. Int J Tech Res Sci 2020;5:27–34. https://doi.org/10.30780/ijtrs.v05.i08.004.

[19] Reig L, Soriano L, Borrachero MV, Monzó JM, Payá J. Potential use of ceramic sanitary ware waste as pozzolanic material. Bol La Soc Esp Ceram y Vidr 2022;61:611–21. https://doi.org/10.1016/j.bsecv.2021.05.006.

[20] Zhang H, Yang Y, Huang J, Fan D. Radiative cooling gray paint with high solar reflectance for thermal management of electronic equipment. Sol Energy 2022;241:460–6. https://doi.org/10.1016/j.solener.2022.06.019.

[21] Tang H, Li S, Zhang Y, Na Y, Sun C, Zhao D, et al. Radiative cooling performance and life-cycle assessment of a scalable MgO paint for building applications. J Clean Prod 2022;380:135035. https://doi.org/10.1016/j.jclepro.2022.135035.

[22] Allaoui D, Nadi M, Hattani F, Majdoubi H, Haddaji Y, Mansouri S, et al. Eco-friendly geopolymer concrete based on metakaolin and ceramics sanitaryware wastes. Ceram Int 2022;48:34793–802. https://doi.org/10.1016/j.ceramint.2022.08.068.

[23] Atabey İİ. Influence of Ca and Al source on elevated temperature behavior of waste ceramic sanitaryware-based alkali-activated mortars. J Aust Ceram Soc 2022;58:949–62. https://doi.org/10.1007/s41779-022-00750-1.

[24] Kinoshita S, Yoshida A. Investigating performance prediction and optimization of spectral solar reflectance of cool painted layers. Energy Build 2016;114:214–20. https://doi.org/10.1016/j.enbuild.2015.06.072.

[25] Qin M, Xiong F, Aftab W, Shi J, Han H, Zou R. Phase-change materials reinforced intelligent paint for efficient daytime radiative cooling. IScience 2022;25. https://doi.org/10.1016/j.isci.2022.104584.

[26] Halicka A, Ogrodnik P, Zegardlo B. Using ceramic sanitary ware waste as concrete aggregate. Constr Build Mater 2013;48:295–305. https://doi.org/10.1016/j.conbuildmat.2013.06.063.

[27] Medinna C, Sanchez de Rojas M., Frias M, Juan A. We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %. Intech 2016;11:13.

[28] Tutkun B, Beglarigale A, Yazici H. Alkali-silica reaction of sanitary ware ceramic wastes utilized as aggregate in ordinary and high-performance mortars. Constr Build Mater 2022;319. https://doi.org/10.1016/j.conbuildmat.2021.126076.

[29] Li LG, Zhuo ZY, Zhu J, Chen JJ, Kwan AKH. Reutilizing ceramic polishing waste as powder filler in mortar to

reduce cement content by 33% and increase strength by 85%. Powder Technol 2019;355:119–26. https://doi.org/10.1016/j.powtec.2019.07.043.
[30] Roushdy MH. Sanitary Ware Waste as a Source for a Valuable Biodiesel Catalyst. J Chem 2022;2022. https://doi.org/10.1155/2022/1232110.
[31] ISO. ISO 1514:2016 paint and varnish standard panel for testing. 2016.
[32] ISO 13320. Particle size analysis — Laser diffraction methods. Int Organ Stand 2009;10406-1:20:9.
[33] Dodds J. Techniques to analyse particle size of food powders. Handb Food Powders Process Prop 2013:309–38. https://doi.org/10.1533/9780857098672.2.309.
[34] Zhang K, Tran I, Tan S. Characterization of Particle-Size-Based Homogeneity and Mycotoxin Distribution Using Laser Diffraction Particle Size Analysis. Toxins (Basel) 2023;15. https://doi.org/10.3390/toxins15070450.
[35] Horiba. a Guidebook To Particle Size Analysis. Horiba 2019:1–17.
[36] Ali A, Chiang YW, Santos RM. X-Ray Diffraction Techniques for Mineral Characterization: A Review for Engineers of the Fundamentals, Applications, and Research Directions. Minerals 2022;12. https://doi.org/10.3390/min12020205.
[37] Singh Y. X-Ray Diffraction in Mineralogical Research. J ISAS 2023;1:1–11. https://doi.org/10.59143/isas.jisas.1.4.wcjb9374.
[38] Ermrich M, Opper D. X-ray Powder Diffraction for the Analyst. 2011.
[39] Bunaciu AA, Udriştioiu E gabriela, Aboul-Enein HY. X-Ray Diffraction: Instrumentation and Applications. Crit Rev Anal Chem 2015;45:289–99. https://doi.org/10.1080/10408347.2014.949616.
[40] Silva TH, Castro ACM, Valente Neto FC, Soares MMNS, De Resende DS, Bezerra ACS. Recycling ceramic waste as a raw material in sanitary ware production. Ceramica 2019;65:426–31. https://doi.org/10.1590/0366-69132019653752687.
[41] Scapin MA, Tessari-Zampieri MC, Guilhen S, Cotrim M. X-ray fluorescence spectrometry: An alternative technique for analysis of waste. Brazilian J Radiat Sci 2023;11:01–8. https://doi.org/10.15392/2319-0612.2023.2144.
[42] Brouwer P. Theory of XRF. PANalytical B.V.; 2010.
[43] Gerodimos T, Asvestas A, Mastrotheodoros GP, Chantas G, Liougos I, Likas A, et al. Scanning X-ray Fluorescence Data Analysis for the Identification of Byzantine Icons' Materials, Techniques, and State of Preservation: A Case Study. J Imaging 2022;8. https://doi.org/10.3390/jimaging8050147.
[44] Tarhan B, Tarhan M, Aydin T. Reusing sanitaryware waste products in glazed porcelain tile production. Ceram Int 2017;43:3107–12. https://doi.org/10.1016/j.ceramint.2016.11.123.
[45] Zhang X, Zhou S, Leonik FM, Wang L, Kuroda DG. Quantum mechanical effects in acid-base chemistry. Chem Sci 2022;13:6998–7006. https://doi.org/10.1039/d2sc01784a.
[46] Harsch H-DB; N. BROENSTED ACIDS AND BASES 2014 (HD Barke 2014).pdf 2014:10.
[47] Tshepelevitsh S, Kütt A, Lõkov M, Kaljurand I, Saame J, Heering A, et al. On the Basicity of Organic Bases in Different Media. European J Org Chem 2019;2019:6735–48. https://doi.org/10.1002/ejoc.201900956.
[48] World Health Organization. Silicon Dioxide , Amorphous Chemical names 2017:0–3.
[49] ASTM D1475. Standard Test Method For Density of Liquid Coatings, Inks and Related Products, ASTM International, West Conshohocken, PA, 2020, URL www.astm.org 2020;i:1–2. https://doi.org/10.1520/D1475-13R20.2.
[50] ISO 2811: 2016. Paint and Varnish Determination of density. 2016.
[51] Mehdipour-Ataei S, Tabatabaei-Yazdi Z. Heat Resistant Polymers. 2015. https://doi.org/10.1002/0471440264.pst636.
[52] Rohm CO, LTD. Application Note Thermal Design (Basic) Basics of Thermal Resistance and Heat Dissipation 2021:1–6.
[53] Ma B, Cheng Y, Hu P, Fang D, Wang J. Passive Daytime Radiative Cooling of Silica Aerogels. Nanomaterials 2023;13. https://doi.org/10.3390/nano13030467.
[54] Peoples J, Li X, Lv Y, Qiu J, Huang Z, Ruan X. A strategy of hierarchical particle sizes in nanoparticle composite for enhancing solar reflection. Int J Heat Mass Transf 2019;131:487–94. https://doi.org/10.1016/j.ijheatmasstransfer.2018.11.059.
[55] Kraus SF. Measuring the Earth's albedo with simple instruments. Eur J Phys 2021;42. https://doi.org/10.1088/1361-6404/abe8e4.
[56] Gray S, Cotta T, Blue R. Solar Reflectance, Thermal Emittance and Solar Reflectance Index (SRI) 2009;100:95354.
[57] ISO. ISO 9050 Glass in building — Determination of transmittance, ultraviolet transmittance transmittance, total solar energy light transmittance, solar direct and related glazing factors. ISO 2003;2.
[58] Rong X, Jiao L, Kong X, Yuan G. Research on low-brightness and high-reflective coatings suitable for buildings in tropical areas. Coatings 2020;10. https://doi.org/10.3390/coatings10090829.
[59] Casini M. Advanced building skin. Smart Build 2016:219–45. https://doi.org/10.1016/b978-0-08-100635-1.00006-x.
[60] Ravenel N, Burks J. Technical Tidbits. MATERION 2018;1:0–1.
[61] Pisello AL. High-albedo roof coatings for reducing building cooling needs. Elsevier Ltd.; 2015. https://doi.org/10.1016/B978-1-78242-380-5.00009-1.
[62] Shakir HMF, Ali A, Zubair U, Zhao T, Rehan ZA, Shahid I. Fabrication of low emissivity paint for thermal/NIR radiation insulation for domestic applications. Energy Reports 2022;8:7814–24.

https://doi.org/10.1016/j.egyr.2022.05.287.
[63] Kalman L. Development of a novel dental thermal imaging application. Med Res Innov 2022;6:1–8. https://doi.org/10.15761/mri.1000184.
[64] A. Skouroliakou, I. Kalatzis NK. Infrared thermography quantitative image processing 2017.
[65] Zhao X, Luo Y, He J. Analysis of the Thermal Environment in Pedestrian Space Using 3D Thermal Imaging 2020.
[66] Yang X, Geng J, Tan X, Liu M, Yao S, Tu Y, et al. A flexible PDMS@ZrO2 film for highly efficient passive radiative cooling. Inorg Chem Commun 2023;151:110586. https://doi.org/10.1016/j.inoche.2023.110586.
[67] S Kam IM. 25.5 Deg C and Human Comfort 2005.
[68] Lawrence T. Turn up the thermostat: lower energy costs, no complaints. UGA Res 2020. https://research.uga.edu/news/turn-up-the-thermostat-lower-energy-costs-no-complaints/ (accessed February 29, 2024).
[69] Guo S, Yang H, Li Y, Zhang Y, Long E. Energy saving effect and mechanism of cooling setting temperature increased by 1 °C for residential buildings in different cities. Energy Build 2019;202:109335. https://doi.org/10.1016/j.enbuild.2019.109335.
[70] Poolsawat K, Tachajapong W, Prasitwattanaseree S, Wongsapai W. Electricity consumption characteristics in Thailand residential sector and its saving potential. Energy Reports 2020;6:337–43. https://doi.org/10.1016/j.egyr.2019.11.085.
[71] Himacharoen J. MEA reveals air conditioner test results The hotter the weather The more power is consumed 2021. https://www.mea.or.th/public-relations/corporate-news-activities/announcement/TyK32m6qm (accessed February 29, 2024).

BIOGRAPHY OF AUTHORS

	Hendra Kustiawan is one of student in Master Program in Environmental Management and Technology, Faculty of Environment and Resource Studies, Mahidol university, Thailand. Hendra Kustiawan is laboratory technician in the laboratory testing of Central for Ceramics Indonesia, having graduated from Sekolah Tinggi MIPA with B.Sc. in chemistry and Analytical Chemistry College in Analytical Chemistry with Diploma III. Email : hendra.kus@student.mahidol.edu
	Narin Boontanon is Lecturer in the Faculty of Environment and Resource Studies, Mahidol University. Narin Boontanon having graduated in Ph.D. in field of Biogeochemistry, M.Sc in field of Chemistry and B.Sc. in field of Chemistry. Email : narin.boo@mahidol.ac.th
	Suwanna Boontanon is Associated Professor in the Department of Civil and Environmental Engineering Faculty of Engineering, Mahidol University. Suwanna Boontanon having graduated in Doctor Engineering in field of Global Environmental Enginering, M.Eng in field of Civil Engineering and B.Eng. in field of Engineering. Email : suwanna.boo@mahidol.ac.th
	Sayam Aroonsrimorakot is Associated Professor in the Faculty of Environment and Resource Studies, Mahidol University. Sayam Aroonsrimorakot having graduated in Ph.D in field of Interdisciplinary Agriculture, M.Sc. in field of Resource Management and Technology of Environmental Management and B.Sc. in field of Agriculture, Occupational Health and Safety and Health Education. Email : sayam.aro@mahidol.ac.th