The Application and Development of Energy-Saving Paint on Roof Steel Plates

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Abstract. Since Framework Convention on Climate Change made in the Earth Summit of 1992 and Kyoto Protocol in 1997, every country has been trying to reduce the emission of carbon dioxide and develop energy-regeneration. For the past decades, Taiwan industries have adopted high-consuming and high-polluted structure designs of architecture, which increases the total cost of industries and leads to serious greenhouse effect. These have caused several negative impacts on practicing the policy of energy saving in Taiwan. Therefore, this study focuses on developing energy-saving paint used on colored roof plates and long-term usage of paint materials through several experiments. After analyzing the test results, this paper has proved that the new developed paint has upgraded the heat resistance of roof plates, which not only saves more electricity but also eases the impact of Kyoto Protocol on Taiwan industries. Most importantly, this new product meets consumers’ demand in long-term development of natural environment.

1. Introduction
Steel deck roofs have advantages in structure safety and serve the function of time-saving construction, so they are frequently used in factories and extended construction on top of buildings. However, since roof sprayed-coating plates are metal with poor heat insulation, another layer of heat-proof material is commonly used on the backside of plates to prevent the increase of indoor heat that causes an overload to air conditioning system which leads to energy waste. This study applies TRIZ (Theory of Inventive Problem Solving) to develop energy-saving paint made of polypropylene resin and conducts heat resistance tests on plates sprayed with the new paint. Through analyzing the difference of heat resistance in various paint, this paper confirms that the new developed paint has improved the total heat insulation of roof plates.

2. Methodology

2.1 TRIZ inventive principles
TRIZ was invented by Genrich Altshuller, in 1946. Based on this, Altshuller furtherly proposed 39 parameters and organized it into 40 inventive principles, which is a breakthrough to traditional
methodologies [1]. After several experts have applied TRIZ to deal with inventive problems in different files, they have gained convincing results that serve significant reference values and contributions in solving inventive problems. During these experiment processes, the experts have also provided some tools and approaches to motivate invention as well as to solve problems that occur during invention. TRIZ is a systematic methodology that upgrades designers’ thinking process and speeds up the procedure of invention [2]. To solve inventive problems via TRIZ is first to identify and specify problems, then to convert problems to similar standard ones according to the methodology provided by TRIZ. Thus, using this standard solution to solve problems.

2.2 The contradiction matrix chart
When designers face a problem in invention or try to improve a feature, most of time, the situation turns out that another feature gets worse. According to Altshuller's analysis, there are totally 39 patterns in the contradictions that commonly occur in invention and Altshuller organized the responding solutions to these contradictions in matrix. The horizontal axis in matrix refers to the negative effects that occur when attempting to get positive effects, while the lateral is the positive effects planned to be improved. Assuming when designers intend to better feature A but causes feature B deteriorating, designers can get solutions from inventive principles and TRIZ contradiction matrix efficiently. The contradiction matrix consists of 39 rows and columns, totally 1521 elements [3]. Table 1 is the chart of the contradiction matrix.

| Deteriorated parameters | Positive Parameters | 01.weight of mobile object | 02.weight of fixed object | 18.Brightness | 39.productivity |
|-------------------------|---------------------|---------------------------|--------------------------|---------------|---------------|
| Parameters | To be improved | | | | |
| 01.weight of mobile object | - | 19.01 | 35.03 | |
| ↓ | ↓ | ↓ | ↓ | ↓ |
| 39.productivity | 35.26 | 28.27 | 26.17 | 19.01 |

2.3 TRIZ method and principle in developing plate paint
This paper is to improve solar reflectance of heat-proof paint. Taking one of TRIZ problem-solving principle used in this study as an example—to upgrade the reflectance of physical property by applying TRIZ contradiction matrix and 40 principles. The brief elaboration is as below. Traditionally to improve reflectance of materials is to use compound heat-proof materials in paint and thicken the paint sprayed on plates. However, in this study, we follow the traditional way to thicken the new paint on backside of roof plates, but it causes small air bubbles between layers of paint, or even making the paint pealing off. It leads to poor out-looking of plates and construction failure. Moreover, thickening heat-resistant materials causes more weight on roof structure and thus plate structures need to be strengthened, which increases construction cost and unnecessary capital burden. Through applying contradiction matrix procedure, a solution is suggested, to change physical property of materials to chemical property that is to add suitable amount of polysilic resin in the mixture of material A-type, polypropylene resin. While mixing these materials, the air within the mixture dries the material, creating small bubbles inside the mixture. After this compound material dries, it gets lighter and has better heat insulation. Through applying TRIZ contradiction matrix and 40 new inventive principles to proceed this revision, this approach improves the physical property of the paint and also advances
the stability of the material. The parameters which need to be improved and deteriorated ones are listed as following: 13. stability of objects, 18. brightness, 26. numbers of objects, 30. harmful elements on objects and 35. suitability, the five parameters in contradiction matrix as Table 2 shown.

Table 2 Contradiction Matrix chart

| Deteriorated parameters | Parameters to be improved | 13. stability of objects | 35. suitability |
|-------------------------|---------------------------|--------------------------|----------------|
| 18. brightness          | (35)                      | (17) , (32)              |
| 26. numbers of objects  | (32) , (35)               | (22) ,(33) , (35) , (40) |
| 30. harmful elements on objects | (33) , (35) | (17) , (30) |
| 35. suitability         | (32) , (35)               |                          |                |

Elaboration: application of TRIZ seven inventive principles
(17) Moving to a New Dimension: replace single layers with multi layers.
(22) Convert Harm into Benefit: transfer harmful elements to be positive.
(30) Flexible Shells and Thin Films: replace original structure with flexible shells and thin films.
(32) Color Changes: change the color of objects or its surroundings.
(33) Homogeneity: use the same materials or related materials to achieve mutual interactions.
(35) Transformation of Properties: change properties of objects, such as their density, temperature and flexibility.
(40) Composite Material: use composite materials to replace homogenous materials

2.4 An introduction of heat-proof paint on plate

2.4.1 An introduction of heat-resistant paint
In the study of Hideki Takebayashi & Masakazu Moriyama indicates [4], the Table 2 in the study mentions solar reflectance (Albedo) of highly reflective white paint is 0.74. The heat reflectance of white color is better than other colors. Thus, white color is used as heat-proof paint for roof plates in this study [5]. This study uses 2 kinds of heat-proof paint materials. The material A, polypropylene resin, is mainly used in adhesives, water-proof materials, protective materials, concrete additives and so on. Material B is heat-resistant powder (aluminosilicate salty) [6], mainly used in water-proof materials, fire-proof materials, concrete additives, retarders and so on [7]. The mixture of these two materials in suitable proportion is a heat-proof material for roof steel plates. This mixture gets solid after it dries due to the three reasons stated as: 1) After mixing, these two kinds of materials cause neutralization of acidity and alkalinity; 2) This mixture in resin breaks surface tension, which allows water to vaporize and speeds up hardening without causing cracks; 3) The mixture has vacant spaces itself which stop thermal conductivity, thermal current and radiation [8].

2.4.2 An introduction of developing heat-proof paint on roof plates
Only two materials are used in this new developed heat-resistant paint. Polypropylene resin, material A, is the common name for Butyl Acrylate, Methyl Methacrylate and Methacrylic acid. It is weak acid. Material A is the emulsified mixture of Polypropylene resin. The production processes are briefly introduced as: 1) Add pure water in reaction tank and then heat up to 70~80℃; 2) Add suitable amount of emulsified materials (anionics surfacing dispersing agents, Sodium Lauryl Sulfate C12H25OSO3Na are commonly used); 3) Mix the materials and put in Monomer; 4) Add initiate agents, such as Ammonium Persulfate(NH4)2S2O3 and Potassium Persulfate(K2)S2O3; 5) Use Na2CO3 to adjust require of PH value; normally PH rate is 7~8; 6) It must be following the reaction demands and it needs the refluenting reaction coagulative pipes, preventing gel phenomena caused by high temperature; 7) After the whole procedure is done, add monomer reaction such as vacuity. Besides,
heat-proofed powder (material B) is the mixture of aluminosilicate salty, silicapearlite powder, titanium dioxide. It is alkalescent.

2.4.3 The special patterns in developing products
Polypropylene resin, material A, is easier to control in production cost and manufacturing process. Furthermore, this type of resin is more stable, which secures the stability of resin, ensuring the reliability of analysis results. The goal of developing this new product is to fit and satisfy customers’ needs. Through the design of Taguchi Quality Engineering, the best combinations of manufacture parameters are formed, thus providing high quality production conditions. Through applying TRIZ theory, the high reflective white ceramic paint is revised. Its interface of thin films is revised and the surface of SixOy-Al coupler agent paint becomes compound films. With these, the best conditions are provided for the development of this new paint. Before a new product is developed, customers’ demands and expectations need to be settled and converted to a requirement in every aspect of production to achieve the goal of satisfying customers [8].

3. Experiment facilities

3.1 The design of the experiment (partially extracted)
The design of boxes in this experiment is based on the Table 3 (The components of a test cell) in the study by T. Soubdhan, T. Feuillard, F. Bade[9]. This study simulates the mould and builds up the boxes (case size: L:124xW: 124xH: 50–146cm). These three boxes in this test consist of iron slotted angles as main frame. The wall of the boxes is made of thick plywoods (10mm thick) sprayed with white heat-proof paint, inner boards of 40mm-thick PS board, and the introduction of sensor installation show as Table 3 shown.

3.2 The measuring method and process
(1) As Table 3 indicated, T-type thermocouple wires measure temperature, hydrometers measure humidity, pyrheliometers measure solar radiation, anemometers take wind speed and heat flow meters take the heat current passing from the roof to the boxes (from 10:00 a.m. to 2:00 p.m.). The frequency of measurement is set once 10 seconds and the average readings are recorded every 10 minutes, which provides a short gap in each measurement and allows thermal conductivity to respond.

(2) The average heat flow in this study is based the data taken during 10 a.m. to 2 p.m. The max average Ui rate is acquired from the heat insulation test of each box.

Table 3 The design of test boxes

| Interior design of test boxes | The location of Sensors in test box | The installation of experiment facilities |
|------------------------------|-----------------------------------|------------------------------------------|

3.3 The calculation of average radiation temperature
The calculation of average radiation heat inside the boxes and temperature taken by bulb thermometers [10]. Indoors heat radiation is usually indicated as average radiation temperature (Tmrt). The average radiation temperature can also be acquired from the temperature taken by bulb thermometers. Belding’s formula can be used to transfer the temperature of average radiation to that of black bulb thermometers. The formula is Tmrt=Tg+2.4V0.5(Tg-Ta). The interior box is a closed space so the
indoor wind speed is zero, which makes the whole formula as \( T_{mrt} = T_g + 2.4V^{0.5}(T_g - T_a) \). \( \therefore T_{mrt} = T_g + 0 \), \( \therefore T_{mrt} \approx T_g \).

4. Test Procedures

With these three boxes, the control group A, and the experimental group B & C, this study performs experiment on the plates with & without the new paint and calculates the readings of thermal conductivity and had the thermal conductivity, \( V \) rate, of heat-proof paint in each group. Through these test results, the improved heat insulation in each group is listed according to its performance as Table 4 to Table 5 shown.

4.1 The heat resistance test of 2 sets in 1st group (partially extracted)

In the three test boxes of each group, the heat resistance test on plates with/without heat-proof paint in 2 sets of 1st group was conducted on sunny day. The heat resistance test result of 2 sets in 1st group is as the test result as Table 4~5 and Fig.1~2 indicated shows.

| Item | 1st set test box (left side) in 1st group | 1st set test box (right side) in 1st group |
|------|----------------------------------------|----------------------------------------|
| test boxes | | |
| paint | A: light green plate. B: light green plate with white SxOy-Al couplier agent paint. C: light green plate with white SixOy-Al couplier agent paint |

Table 4 The records of heat-proof paint in 1st set of 1st group

| Item | 2nd set test box (left side) of 1st group | 2nd set test box (right side) of 1st group |
|------|----------------------------------------|----------------------------------------|
| paint | A: light green plate. B: light green plate with white SxOy-Al couplier agent paint. C: light green plate with white SixOy-Al couplier agent paint |

Table 5 The records of heat-proof paint in 2nd set of 1st group (partially extracted)

4.2 The heat resistance test result of 2 sets in 1st group

As Fig.1 and Fig.2 showed, the difference is existed in the curve line of heat resistance test results of 2 sets in 1st group.

Fig.1 The curve line of heat resistance of the 3 colored plates in 1st set in 1st group

Fig.2 The curve line of heat resistance of the 3 colored plates in 2nd set in 1st group
4.3 The analysis of 1\textsuperscript{st} set (1\textsuperscript{st} group) test result
As Table 4 and Fig.1 indicated, 1) The temperature difference on the surface of A and B plates is 13.92°C on average, B & C is 0.39°C, and A & C is 13.98°C on average. The surface reflectance of plates C is better than plates A and B. 2) The heat resistance of paint on plates A is 0.71°C and that of plates B is 3.68°C while C is 4.88°C on average. Compared with plates A, the heat resistance of plates B improves 81%. The heat resistance of plates C improves 25%, compared with plates B. The heat resistance of plates C is 85% better than that of plates A. This indicates plates C with white SixOy-Al couplier agent paint serve better heat resistance. 3) The temperature taken by the bulb thermometers of box A is 39.22°C, that of box B is 28.84°C while Box C is 28.49°C. Compared with box A, the radiation in box B improves 26%. The radiation of Box C improves 1.2%, compared with Box B. The radiation of Box C is 27% better than Box A. This indicates plates C with white SixOy-Al couplier agent paint serve better heat resistance.

4.4 The analysis of 2\textsuperscript{nd} set (1\textsuperscript{st} group) test result
As Table 5 and Fig.2 indicated, 1) The temperature difference on the surface of A and B plates is 14.07°C on average, B & C is 0.07°C, and A & C is 14.09°C on average. The surface reflectance of plates C is better than plates A and B. 2) The heat resistance of paint on plates A is 1.29°C and that of plates B is 3.78°C while C is 4.03°C on average. Compared with plates A, the heat resistance of plates B improves 66%. The heat resistance of plates C improves 6%, compared with plates B. The heat resistance of plates C is 68% better than that of plates A. This indicates plates C with white SixOy-Al couplier agent serve better heat resistance. 3) The temperature taken by the bulb thermometers of box A is 40.07°C, that of box B is 29.72°C while Box C is 29.69°C. Compared with box A, the radiation in box B improves 26%. There is no obvious difference between radiation heat of box C and B. The radiation of Box C improves 26%, compared with Box A. This indicates Box C has lower radiation.

4.5 Summary
From the curve lines of each group, the light green plates sprayed with new developed SixOy-Al couplier agent paint in the one sets of 1\textsuperscript{st} group has the best improvement in heat resistance test, also improved a lot in total heat resistance. The application of new developed paint on roof plates: the application records of the new developed heat-proof paint and the spraying procedure is as Table 6 shown.

| Processes of spraying paint on roof plates-1 | Processes of spraying paint on roof plates-2 | Processes of spraying paint on roof plates-3 (finishing spraying) |
|--------------------------------------------|--------------------------------------------|---------------------------------------------------|
| ![Processes of spraying paint on roof plates-1](image1) | ![Processes of spraying paint on roof plates-2](image2) | ![Processes of spraying paint on roof plates-3 (finishing spraying)](image3) |

5. Discussion

5.1 The test results of the 2sets in 1\textsuperscript{st} group
The test results of the 2sets in 1\textsuperscript{st} group are organized and compared as Table 7 and Table 8 show. As the announcement from Taiwan Economics department indicates, every 1 °C drop in room temperature saves 6% electricity bill.
Table 7 The test result analysis of 2 sets in 1st group

| group | Color of plate | Heat resistance of the paint (℃) | Radiation heat inside the box (℃) | Level of performance | Temperature Difference in each group | Saving of electricity bill |
|-------|----------------|---------------------------------|----------------------------------|----------------------|-----------------------------------|-------------------------|
| 1-A   | light green plate | 0.71                            | 39.22                            | 3                    | 10.73℃                           |                         |
| 1-B   | Light green plate with white SxOy-Al couplier agent paint | 3.68                            | 28.84                            | 2                    | 64.40%                           |                         |
| 1-C   | Light green plate with white SxOy-Al couplier agent paint | 4.88                            | 28.49                            | 1                    |                                   |                         |
| 2-A   | light green plate | 1.29                            | 40.07                            | 3                    | 10.38℃                           |                         |
| 2-B   | Light green plate with white SxOy-Al couplier agent paint | 3.78                            | 29.72                            | 2                    | 62.3%                            |                         |
| 2-C   | Light green plate with white SxOy-Al couplier agent paint | 4.03                            | 29.69                            | 1                    |                                   |                         |

Analysis of the test results of the two groups: SixOy-Al couplier agent heat-proof paint has better heat insulation estimated saving of electricity bill 63.35%

5.2 The formula of thermal conductivity $U_i$

The formula of $U_i$ rate for heat resistance in each group is as the R.O.C regulation of energy-saving for buildings, the average $U_i$ rate is acquired as Table 8 shown. (Lin, 2005).

5.3 Comparison and analysis of average $U_i$ rate

Table 8 shows the comparison and analysis of average $U_i$ rate in each group.

Table 8 The comparison of $U_i$ rate in 2 sets of 1st group

| Plate no. | Plate color | Plate thickness (mm) | Paint thickness (mm) | Average thermal conductivity ($U_i$ rate) | Level of performance |
|-----------|-------------|----------------------|----------------------|------------------------------------------|----------------------|
| 1         | light green plate | 0.45                | neglected            | 4.77                                    | 3                    |
| 2         | light green plate with white SxOy-Al couplier agent paint | 0.45                | 0.65                 | 3.00                                    | 2                    |
| 3         | light green plate with white SxOy-Al couplier agent paint | 0.45                | 0.65                 | 1.91                                    | 1                    |

6. Conclusion

This paper applies TRIZ (Theory of Inventive Problem Solving) to develop new white heat-proof paint for colored steel deck plates and has the study results stated as below.

(1) As the announcement from Taiwan Economic department indicates, every 1℃ drop in room temperature saves 6% electricity bill. From the comparison of the test results of 2 sets in 1 groups, the radiation heat of inner wall taken by bulb thermometers drops around 10.38~10.73℃, which saves about 63.35% of electricity bill.

(2) From the average thermal conductivity rate, $U_i$ rate (as Table 8 show), the two sets with new developed paint in 1st group have obvious improvement in total heat resistance. As to the two sets of the 1nd group, the light green plates with white SxOy-Al couplier agent and ceramic paint have the lowest radiation temperature taken by bulb thermometers installed on inner walls, which means this roof plate paint has the best heat resistance.

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