

# Development of Paint and Painting Method for Magnetically Formed Decorative Painting with Enhanced Three Dimensionality

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## ABSTRACT

This development was aimed at the creation of the method of magnetically formed decorative painting applied to the outer parts of motorcycles to realize a larger degree of three-dimensional appearance. First, the conditions required for the orientations of the metallic flakes contained in the paint were investigated. Following to that, the method to realize those orientations was examined. Based on the results, the paint and the painting method were developed to enhance the controllability of the flakes' movements while painting. To make the flakes movable more easily, a high magnetic permeability material was adopted as the flake material. In addition, to make the flakes promptly stop after required amount of movements, a high molecular weight resin was added. Moreover, application of the optimized setting of the thinner further enhanced the controllability of the flake movements. By combining these methods, the decorative patterns with the larger degree of three-dimensional appearance were successfully realized under the conditions of mass production lines.

## 1. Background and Objectives

The markets of motorcycles are predominantly deploying in Southeast Asian countries and are continuously growing in these days. A large number of models are released in these markets from each manufacture of motorcycles. Figure 1 illustrates some of the vehicles released in the markets. Many of the motorcycles sold in these regions are getting more areas on their plastic outer coverings, which are concealing the vehicle body, in association with the demands of the vehicle exterior design variations. The decorating method of plastic coverings is becoming one of the technical factors of greater importance than ever to enhance the attractiveness of the products.



Fig. 1 Examples of small motorcycle models

The commonly applied decorative methods are painting and graphic marks, which are drawn with artistic patterns and affixed on the painted surface (Fig. 2). There are various kinds of painting methods. Some of them have brilliant colors and some other kinds have appearances with high illuminance. There are various kinds of graphic marks as well. However, either of those methods has been used for quite a long time of the history and too much familiarized by the customers.

With this background, there is a strong demand for a method of decorating plastic coverings that can provide a novel appearance never experienced before. On the other hand, graphic marks tend to be considered as decorations created by a simple way without any sophistication because there is no significant difference in appearance from the decorations by generally available stickers. Consequently, it has been highly expected to develop a different method from conventional ones that can offer the appearances with

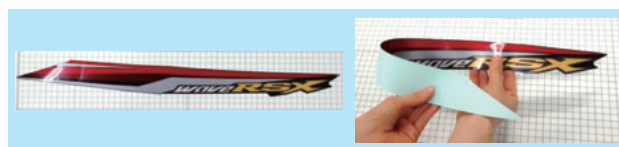


Fig. 2 Example of graphic mark

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a perception of high quality. In our development, a method was investigated to enhance the attractiveness of vehicle appearances by applying a magnetically formed decorative painting on plastic outer coverings<sup>(1),(2)</sup>.

Magnetically formed decorative painting is a method of painting that uses a paint containing small metallic leaves (i.e. flakes) having a magnetic permeability and is conducted while attaching behind the painting object a sheet of a material, such as a magnetic sheet, that generates lines of magnetic force. Magnetically formed decorative painting itself is one of the existing painting methods. However, there used be various obstacles for its application to mass produced products. One of such obstacles is that, during the painting procedure, it needs to have magnet sheets engaged to the parts of plastic coverings. Therefore, it was not practically implemented as a painting method applied to motorcycle parts. Nonetheless, we devised a method to overcome the issues involved in this magnet sheet engagement and accomplished the mass production of the motorcycles applying with this painting method in Thailand in 2008 (Fig. 3).

By applying magnetically formed decorative painting, the figurative patterns with the appearance like the representations made by manual drawing with an airbrush can be created. Moreover, the created patterns represent the appearance having a depth despite its small thickness of the paint layer placed on a flat surface without any dents or protrusions.

The key that enabled the application to the mass production in 2008 was to use a flexible magnetic sheet as the magnetic field generating material to be attached to the part while painting. By applying this painting method, the perceptions of a novel and high quality decoration with three-dimensional decorative patterns were successfully achieved.

Based on this success in application, the request from the market evolved to request for providing even higher degree of three-dimensional appearances that attracts people while the vehicle is in motion as well. Accordingly, the goal of this particular development was set to establish a method

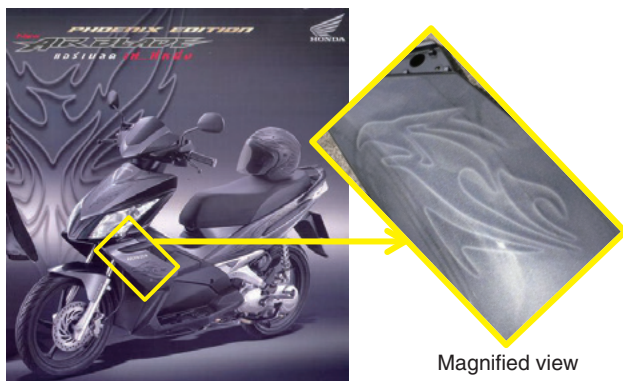


Fig. 3 Mass production model (2008, Thailand)

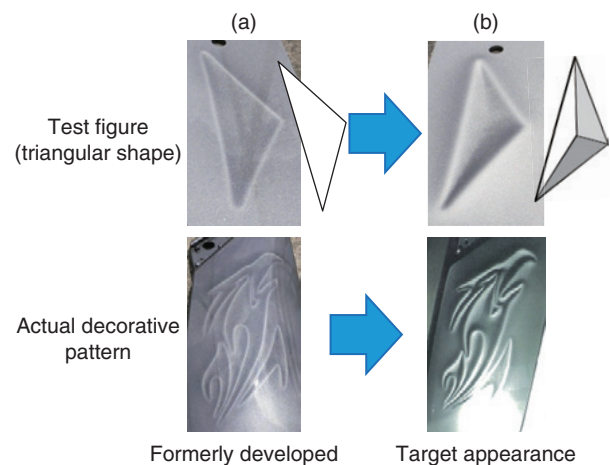
of magnetically formed decorative painting that provides higher three-dimensional appearances than former methods through the enhancements of paint formula and painting process.

## 2. Defining Requirements

### 2.1. Definition of Three-dimensionality

On the surface that is painted with a magnetically formed decorative painting, a kind of optical illusion brings about the effect that presents appearances having virtual depths that makes observers perceive three-dimensional objects without actual substances. In this paper, this “illusive effect that presents three-dimensional appearance” is called “Plasticity” (a term used in pictorial arts). It is considered that the decorative pattern stands out significantly if this illusive effect can be designed to appear more strongly.

The target “plasticity” in this development was expected to have a characteristic of generating the optical illusion over the whole area surrounded by the perimeter of the figurative pattern. Figure 4 (a) shows the appearance of the pattern equivalent to that of the formerly developed product. On the other hand, (b) shows the appearance of the pattern with the plasticity level of the development goal aimed this time. When the appearances of the patterns created using a triangular magnetic sheet are compared, in the case of (a), only the surrounding perimeter of the triangular pattern shows three-dimensional appearance and the inner part of the triangular pattern presents a flat appearance. On the other hand, (b) looks like its inner area of the triangular pattern is presenting an appearance of a trigonal pyramid with three-dimensionality. The pattern as shown in (b) was



- (a): It is representing insufficient perception of depth as the area of high luminosity is limited only around the area just adjacent the perimeter.
- (b): It is representing the perception of depth with gradual changes of the brightness ranging over the area within the perimeters of the triangle.

Fig. 4 Plasticity defined as development target

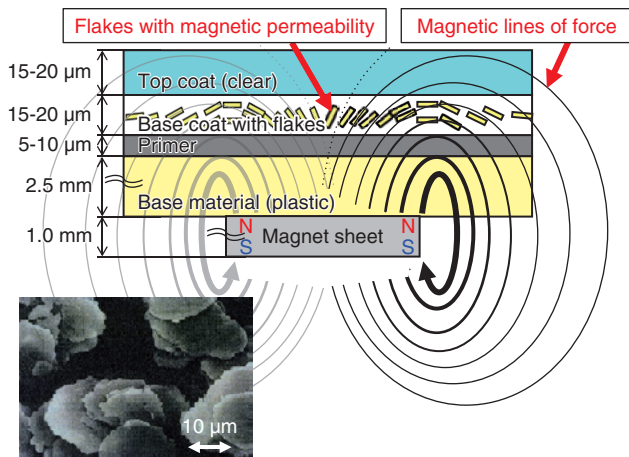
defined as the pattern with a higher plasticity. The reason why the pattern is perceived like a three-dimensional trigonal pyramid is that the light intensity of the inner area, which is under the influences from the applied magnetic fields, varies depending on the observing angles inducing the effect of manifestation of the depth in the appearance. From the comparison between (a) and (b), it is considered that an observer perceives the depth of the pattern when it has a larger area of varying intensities of reflected light within the area surrounded by the triangle.

## 2.2. Mechanism of Presenting Three-dimensional Appearances

### 2.2.1. Hypothesis for phenomenon of manifestation

An attempt was made to clarify the structural configurations that constitute a paint layer providing three-dimensional appearances through the investigations on various paint layers produced under different conditions by implementing pre-established methodology. In general, when a paint using flakes is applied, the flakes are usually contained in the base coat, which is applied after painting a primer. Following to that, after the application of the base coat, a method is usually used in which a clear top coat is applied to provide a glossy appearance to the paint surface. In the same way, the paint layers of a magnetically formed decorative painting are structured with three coatings of primer, base coat and top coat as shown in Fig. 5.

In the base coat layer of magnetically formed decorative painting, the flakes are situated with predetermined angles being parallel with the directions of the lines of magnetic force generated from the magnetic sheet attached behind the



The magnetic lines of forces (magnetic fields) originate at the N-pole and reach the S-pole by traveling along circular lines. The magnetically permeable flakes are aligned along those lines.

Tesla is used as the unit for describing the density of magnetic field (the index for strength of a magnet), where one tesla is ten thousand gaussers.

Fig. 5 Assumed principle of flake pattern generation in magnetically formed decorative painting

part. It is understood that the three-dimensional patterns are generated by this structure. Moreover, the intensity of the reflected light from the flakes, which have a distribution of orientation angles, changes depending on the viewing angle of an observer of the decorative pattern. In association with those changes in viewing angles, the brightness of each part in the pattern varies. Accordingly, it was assumed that change of brightness makes it look three-dimensional (Fig. 6). To substantiate this assumption, two kinds of experiments were conducted as described below.

### 2.2.2. Measurement of light intensity variations

At the beginning, variations in the distribution of reflected light to the changes of the observation angles were examined. For the measurement, a variable-angular photometer that measures light intensities while varying the detection angle was used. The detailed explanations on descriptions used in this paper, such as light intensity, luminosity or luminous intensity, are presented in Appendix 1. A magnetically formed decorative paint was applied while attaching a magnetic sheet in isosceles triangular shape with the base length of 100 mm and the base angles of 30 degrees. Measurements were conducted to the patterns appeared after the paint application (Fig. 7). This triangular shape was used as the common base figure

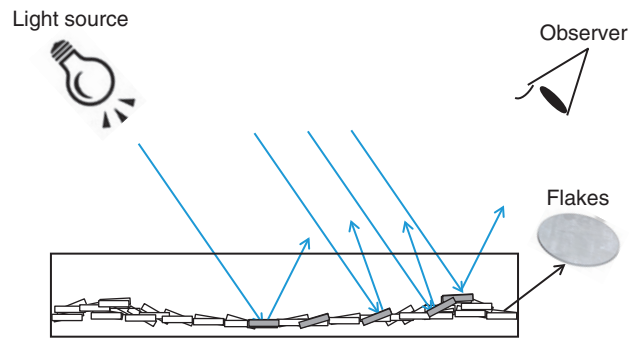
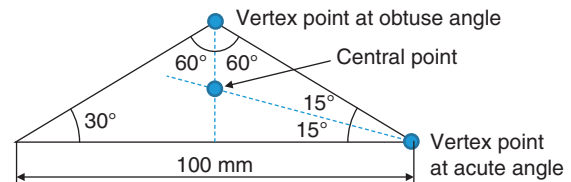


Fig. 6 Presumption of the reason why magnetically formed decorative painting appears three-dimensional



| Measurement point            | Intensity of magnetic field (mT)* |
|------------------------------|-----------------------------------|
| Central point                | 4.0 – 8.0                         |
| Vertex point at acute angle  | 9.0 – 15.0                        |
| Vertex point at obtuse angle | 7.0 – 12.0                        |

\* Measurement equipment: Tesla Meter (TM-601, KANETEC Co., Ltd.)

Fig. 7 Standardized specifications of magnetic sheet for testing

for the following measurements.

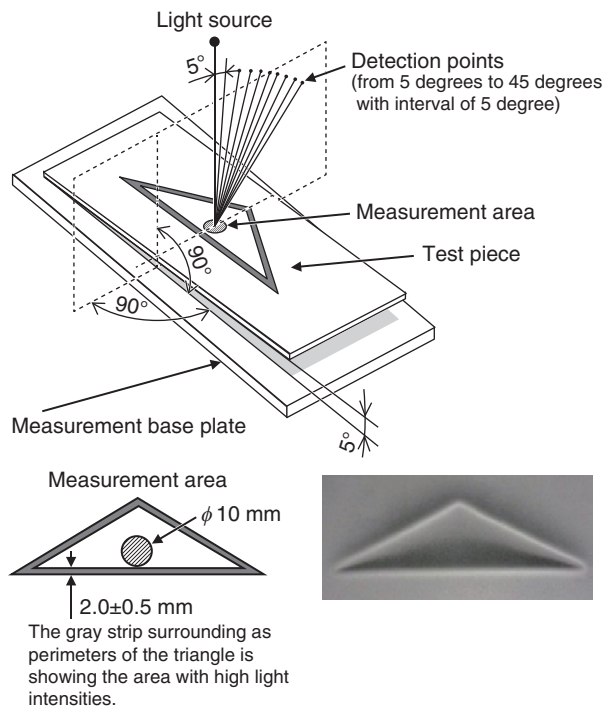
Figure 8 illustrates the measurement method. The light intensity from the paint surface painted with magnetic sheet of the aforementioned shape attached on the back side of an ABS resin plate of 3 mm thickness was measured. The distribution of the light intensity reflected from the hatched circular area of 10 mm diameter, shown in Fig. 8, was measured. This part is the area where the variations of the light intensities of the pattern are largely demonstrated. For this measurement, the area adjacent to around the perimeter of the triangle was excluded from the target area of the measurement, because variations of light intensity are small because of an unchanging high intensity of the light in this area. In addition, the measurement for a general metallic painting was also conducted to make a comparison.

The light source was located vertically above the base plate of the measurement equipment. The test piece was placed so that it was slanted to the plane of measurement base with an angel of 5 degrees as shown in Fig. 8 to avoid the direct reflection of the light. The results of the angular distributions of the reflected light measured by this method are shown in Fig. 9. In the case of conventional metallic painting, the light intensity becomes significantly large at around the angle close to that of the direct reflection (at the angle of 5 degrees) but it abruptly goes down when the detection angle is shifted from that angle. In the case of the magnetically formed decorative painting, it was confirmed

that the light intensity was not suddenly decreasing but was gradually changing when the detection angel was varied. As it had been expected, it was understood that the angles of flakes in the layer of magnetically formed decorative paint had a broadly spread distribution. Observing angles for the decorative pattern correspond to the angles for the detection of the measurement. Consequently, based on the results from the experiment, it was confirmed that the appearance exhibited by the variations of the reflected light when the decorative pattern was observed corresponded to the representations of the light intensity distribution.

### 2.2.3. Flake angles and brightness changes derived from magnetic field

In the next step, the relationship between flake angles and the reflected light intensities was investigated. Test pieces to be examined were prepared using a magnetic field generator shown in Fig. 10. The preparation procedures are described as follows. An apparatus structured to provide lines of magnetic force with the same direction was arranged. In that apparatus, spacing was provided so that a plastic plate of 10 by 40 mm in size could be placed in that gap. A plastic plate painted with a paint containing magnetic flakes was set in this spacing before drying.



Measurement with variable-angular photometer and measured area (GP200, Murakami Color Research Laboratory)

Fig. 8 Methodological configuration of measurement using variable-angular photometer

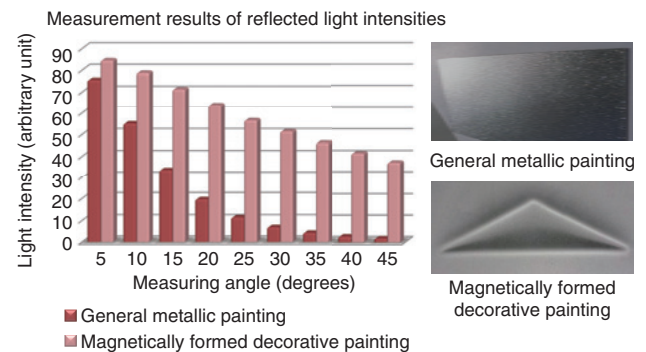


Fig. 9 Measurement results of angular distributions of reflected light intensities detected by variable-angular photometer

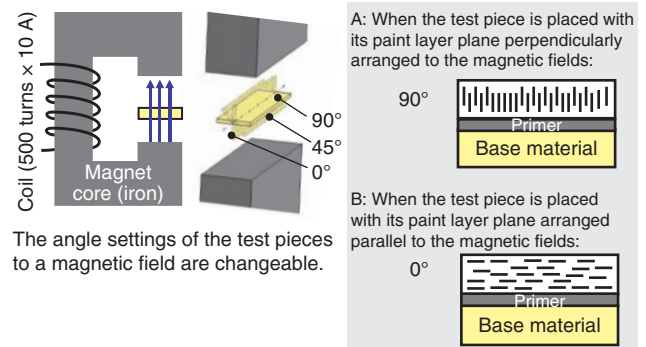


Fig. 10 Apparatus to examine directional relationship between magnetic lines of force and flakes

The directions of the lines of magnetic force are equally oriented to a single direction for any place within this spacing. Therefore, if the flakes change the slanting angles aligning to the line of magnetic force, it was assumed that almost all the flakes located within this space were equally oriented to the same direction (as shown in the figures on the right in Fig. 10). Without changing the direction of the lines of magnetic force on the apparatus, plastic plates were placed in it so that each orientation of those plates was directed to the five kinds of angular settings of 0 degrees (parallel), 30 degrees, 45 degrees, 60 degrees or 90 degrees (perpendicular). Using these plastic plates, the test pieces were prepared to examine the variations of reflected light intensities from the paint layer that had been exposed with magnetic fields of different directions.

The largest intensity was observed, as shown in Fig. 11, for the plate that had been placed in parallel to the direction of the lines of magnetic force (at 0 degrees). On the contrary, when the plate had been placed vertically to the direction of magnetic field (at 90 degrees), almost all the flakes represented the state of being standing perpendicularly to the paint surface plain. In this case, the coating applied underneath (which is the primer layer with black color) could not be concealed by the flakes representing the lowest intensity of the reflected light as a result. Accordingly, it was revealed that a large difference occurs in the magnitude of reflected light intensities from the test pieces between the one having set in parallel and the one having set vertically. In addition, on the pieces with the set angles in between, the brightness varied depending on the angles at which the plate had been set against the direction of the magnetic field and gradational changes of the light intensity were observed. The gradational changes of light intensities presented in the test were in the same manner manifested by those in the pattern created by application of the magnetically formed decorative painting. Based on those results, it is considered that the variation of the light intensities at the part of the decorative pattern is

caused by the arrangement of the flakes with slant angles varying in association with the directional changes of the lines of magnetic force.

Moreover, when the cross sections of the paint layers of those test pieces were actually observed with a microscope, the flakes are situated having the same direction with a particular angle of the imposed magnetic field as shown in Fig. 12. Consequently, it was confirmed that the gradational appearances observed at the decorative pattern were generated by the variations of flake angles.

## 2.2.4. Mechanism that presents three-dimensional appearances

Through the measurement results of these two experiments, it was verified that the flakes contained in the paint layer were aligned in parallel to the direction of the lines of magnetic force and the intensity of the reflected light varies depending on the observation angles. The mechanism described above is considered to be the reason why the patterns created by the magnetically formed decorative painting represent three-dimensional appearances.

## 2.3. Defining Target Plasticity

In this chapter, numerical levels for evaluating the plasticity are defined and the target level is clarified. The samples were fabricated with consideration of the relationship between the flake arrangement, which influences the degree of plasticity, and the light intensity described before. These samples were investigated to define the indices of plasticity. The target plasticity level was decided by exterior designers by observing the appearances.

### 2.3.1. Preparation of samples for evaluation of appearance define target plasticity level

As it was mentioned in the paragraph 2.2.2, when compared to a conventional metallic painting, a noticeable characteristic of a magnetically formed decorative painting is that the intensity of the reflected light does not decrease suddenly but changes gradually when the detecting angle

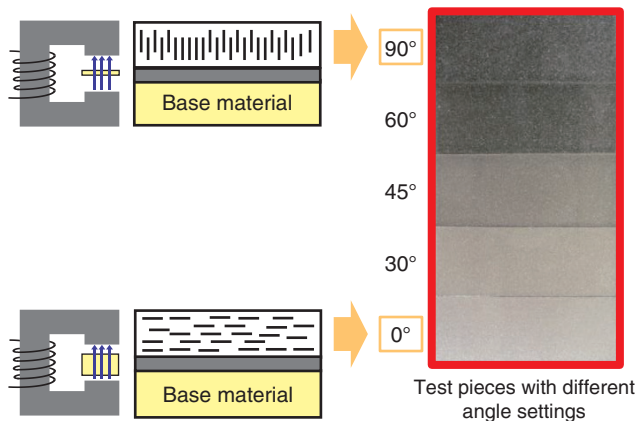


Fig. 11 Light intensity differences among test pieces when varying angle settings to magnetic field

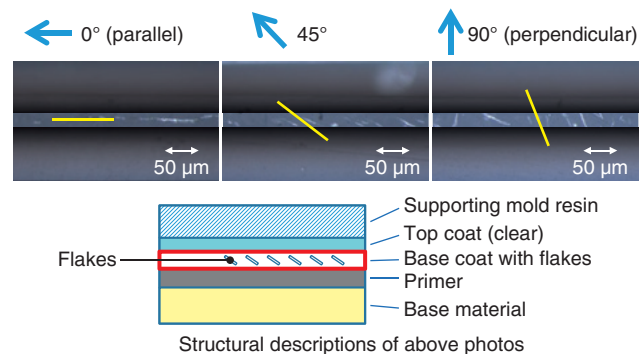


Fig. 12 Cross sectional views of painted layers of test pieces

is shifted. The plasticity represented by the pattern is more enhanced if the area within the pattern where the light intensity changes depending on the variation of observation angles is larger. In order to get a larger area for this light intensity varying region, the area in which the flakes move to align with the directions of the lines of magnetic force must range over a broader area. To fulfill that requirement, the painting method is necessary that satisfies the condition in which the flakes are easy to move in a large area. For preparation of the samples, this must be taken into account.

As one of the methods that realize the abovementioned condition, there is a method that elongates the duration of the flake movements. To implement this method, a thinner that has a slower evaporation speed was used. Thinners with stepwise different evaporation speeds had been prepared and five different test pieces were produced. (The production method and detailed conditions are described in Appendix 2.) The conditions of thinner evaporation speed applied for the test piece fabrication were those only for making test pieces used for visual evaluations to identify the degree of target plasticity, and those conditions were determined without considering the process actually applied to the manufacturing process of the painting. In other words, the samples for the tests were made giving priority to yielding the desired plasticity but without consideration on the time needed for drying.

### 2.3.2. Defining numerical levels of plasticity and setting target level

As it was mentioned before, the plasticity level differs depending on the magnitudes of the light intensities measured at individual detecting angles. Accordingly, for the test pieces made as described in the paragraph of 2.3.1, the variations in light intensities at individual detection angles were examined. The measurement method was the same as that shown in the paragraph 2.2.2. Regarding the target measurement area, it was also set the same as in the paragraph 2.2.2, which was the area away from the perimeter by some distance. Thus, the intensities of the light were measured varying the detection angle.

The absolute values yielded through the measurements on individual test pieces cannot be directly compared because they may be varied depending on the test piece fabrication conditions. The parameter that plays an important role for evaluation of the plasticity is not the absolute value of the observed brightness but is the relative variation ratio. Therefore, the comparisons between relative values are the effectual way of the investigation. Consequently, in this evaluation process, the individual data lines are parallel shifted properly in the direction of the vertical axis of the graph so that the beginning points of the measurement (at the detecting angle of 5 degrees) meet to each other as shown in Fig. 13. In this manner, the variations of the light intensities (L) in different test conditions are effectively compared relatively based on the predetermined fix point of measurement at 5 degrees.

Table 1 Coefficients of inclination calculated by linear approximation for individual test pieces

|              | Inclination of approximation line |
|--------------|-----------------------------------|
| Test piece 1 | -0.46                             |
| Test piece 2 | -0.82                             |
| Test piece 3 | -1.06                             |
| Test piece 4 | -1.22                             |
| Test piece 5 | -1.60                             |

Table 2 Plasticity classification defined by coefficients of inclination calculated by linear approximation

| Plasticity level | Inclination of approximation line (/degree) |
|------------------|---------------------------------------------|
| 4                | -0.49- 0.00                                 |
| 3                | -0.99- -0.50                                |
| 2                | -1.49- -1.00                                |
| 1                | -1.50 or lower                              |

The purpose of this evaluation is to investigate the differences among the test pieces comparing variations in brightness at the inner area of the triangular shape of the decorative patterns. The condition that provides high plasticity, as mentioned in the paragraph 2.2.2, can be translated as the degree of “How much gradually the intensity of the light varies.” Linear approximate equations were calculated based on the plotted points yielded through these measurements. The degrees of variations in the light intensities were indicated by the degrees of slope inclinations of those approximation lines. The values of slope inclinations of the approximation lines for the prepared five kinds of test pieces are shown in Table 1.

By sorting out those approximation lines by grouping with increments of 0.5 of inclination value, four ranges were defined (Table 2). These four ranges were defined as the plasticity levels and they were understood as such the larger

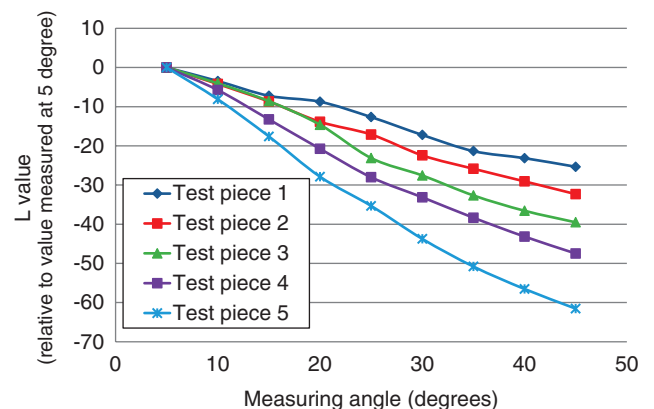


Fig. 13 Comparison of five test pieces with different plasticity levels evaluated by intensity distributions in the areas inside the triangular shape

the value is the higher the plasticity is. Visual evaluations of plasticity were conducted by exterior designers on the five kinds of test pieces. Based on the evaluations, positively rated results were referred to the four ranges defined above. Through the results, it was concluded that the plasticity to be defined as the target index for the development dealt with in this research is classified in “level 3” or above of the defined plasticity scales. Eventually, this level was set as the target requirement for the development.

### 3. Selection of Materials to Achieve Objectives

#### 3.1. Presumption of Flake Arrangement that Fulfill Objectives

Investigations were conducted to identify the way in which the flakes should be actually arranged to achieve the plasticity goal of level three which was determined as described in the previous section.

Firstly, it was investigated how the flake angles and the brightness of the paint layer relate to each other. As shown in Fig. 14, triangular pattern (a) of the upper left in the figure that is presenting a lower degree of plasticity and triangular pattern (b) of the upper right in the figure that is presenting a higher degree of plasticity are compared. As described before, (b) looks like a flat plane in its inner area while (a) looks a concaved trigonal pyramid. Accordingly, it looks like as if the flakes are arranged in the manner shown in the figure at the second low in Fig. 14. (In this paper, this cross sectional plane of the imaginary object is called virtual cross section.) Based on the results shown in the paragraph 2.2.2 and the results on the relationship between a flake angle and the reflected light intensity shown in the paragraph 2.2.3, the shapes of the flakes that were supposed to appear on the cross section of the paint layer were assumed. The actual paint layer has only a thin thickness of 20  $\mu\text{m}$ . Consequently, it is assumed that the flakes are arranged with respective angles as shown in the cross sectional shapes illustrated in the third row of Fig. 14. It is understood that these flakes are slanted to hold the same angles as the angels appeared at corresponding positions in the virtual cross section and are distributed in the paint layer. Thus, the plasticity is considered to be observed because of the reflected light intensities from the flakes that are distributed varying their angles, i.e., because of the differences in the reflected light intensities that vary depending on the positions in the paint layer. Moreover, unlike an ordinary painting, the distribution of the light intensities changes according to the observed angle. As a result, the appearance that is close to the real object is manifested. Subsequently, the difference in flake angle arrangements relative to the lines of the applied magnetic force is shown in the figure at the lowest row of Fig. 14. As shown in the figure, it can be assumed that the flakes are mostly arranged parallel to the line of magnetic force for a high plasticity pattern while only a part of the flakes are arranged parallel to the line of magnetic force for a low

plasticity pattern. This can be translated that it is because the flakes could not fully move to change their angles. The detailed explanation of this matter will be described later.

Based on these investigations above, to realize a high plasticity through magnetically formed decorative painting, a paint and a painting method are required that enable the flakes in larger area in a decorative pattern to fully change their orientations along the lines of magnetic force.

#### 3.2. Methodology to Make Flakes Easy to Move and Associated Issues

##### 3.2.1. Investigating methodology

As mentioned in the previous section, if the necessary conditions are prepared to make the flakes in the paint layer to move easily to align towards the directions of the lines of magnetic force, the angular arrangement of the flakes becomes ideal situation and the decorative pattern with a higher plasticity can be created. There are three measures for helping the flakes to change their orientations, that is to say, for facilitating the movements of the flakes.

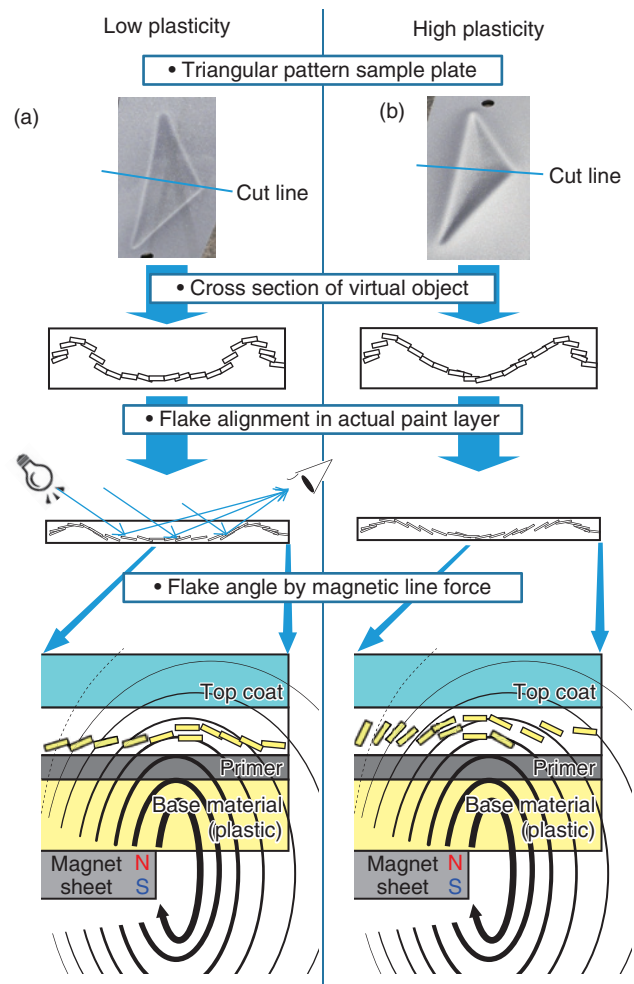


Fig. 14 Relationship of plasticity with flake angle and light intensities

Measure 1: To extend the time for flakes to move by using a thinner with low evaporation speed. (The same method used for preparing the test pieces for defining the level of target plasticity.)

Measure 2: To enhance the force to drive the flakes' mobility by using a magnetic sheet with a stronger magnetic force.

Measure 3: To enhance the flakes' sensitivity to the magnetic force by using a flake material with a higher magnetic permeability.

In the following, the detailed explanation and the associated issues are described for each of these measures.

Measure 1: Using a thinner with low evaporation speed.

The plasticity of the decorative pattern becomes good when the evaporation speed of the thinner is slow. However, at the same time, an ample time is given to the flakes in the area without a pattern as well to change their orientations. That results in potentially high risk of generating a disorder of flake orientation arrangement reflecting any subtle unevenness of the property on the target part surface. In addition, with the this slow thinner condition, it is highly possible, because of the limited tact time for production process, that the painting part is transferred to the next step process (i.e., the top coat painting process) before the base coat is fully dried in the actual production line. In that case, the top coat paint permeates through the base coat to deteriorate the necessary glossiness as a result. In addition, the resulting elongation of the period for flake to move may cause a gloss loss (loss of glossiness) to become another issue of the appearance. Regarding gloss loss, the detail will be described later.

Measure 2: Using a magnetic sheet with a stronger magnetic force.

Currently, magnet sheets are widely used for various applications. Generally speaking, magnet sheets used for stationery, and so on, are magnetized so as to have S poles and N poles in turn on the same side of the sheet. However, the magnet sheet used for the painting of this development is magnetized to have S pole on the whole area of its one side and N pole on all of the other side. For the magnet sheet magnetized in this manner, a special method has to be devised to enhance the magnetic force. This results in increase of the const. Meanwhile, there is another way to enhance the magnetic force without changing magnetizing method but by increasing the sheet thickness. However, many of the plastic covering parts used in motorcycles have complex shapes with protrusions and dents. Therefore, if the sheet thickness is increased, it becomes difficult to affix it closely to the rear side of these plastic coverings. Under those constraints from cost and production process, it is required to use the magnetic sheet with thickness of 1 mm that has been used from before. In addition, the enhanced magnetic force contributes to make the flakes erect in the central area of a decorative pattern. This potentially leads to the generation of a gloss loss resulting in failure to meet the requirements for appearance.

Table 3 Applicable options of measures to create good plasticity

| # | Measures                    | Issues on production process                     | Issues on product quality  |
|---|-----------------------------|--------------------------------------------------|----------------------------|
| 1 | Slow volatilization thinner | Excessively long tact time                       | Gloss loss at central area |
| 2 | Strong magnetic sheet       | Unacceptably costly or too thick to fit on parts | Gloss loss at central area |
| 3 | High permeability flakes    | None                                             | Gloss loss at central area |

Measure 3: Using a flake material with a higher magnetic permeability.

There is no issue arisen regarding production process when this measure is applied. However, it has the issue of the gloss loss generation leading to deterioration of appearance quality, which is the same as the cases of applying measures 1 or 2. The application of high magnetic permeability flakes makes the flakes further susceptible to the lines of magnetic force and more affected by them. As a consequence, the flakes have a higher tendency to stick together to form a chain status. Mostly in the central area of the decorative pattern, the flakes stand towards the surface plane of the painted layer. At the same time, the flakes form chain connection status to stick out from the interface of coatings generating a gloss loss. The same method had been investigated in the production in 2008 as well but any effective countermeasure had not been found to fulfill the requirements both for a good plasticity and a quality of appearance.

Table 3 summarizes the descriptions on individual measures and the respective issues involved. In the development conducted this time, it was hardly possible to apply Measure 1 or Measure 2 that has issues in relation to the production process and/or the cost. Accordingly, the possible option to apply is only Measure 3 in which high magnetic permeability flakes are used. Eventually, it was decided to apply this measure to develop a method that would overcome the generation of a gloss loss and successfully achieve the development objectives.

### 3.2.2. Selection of high permeability flake material

The applicable metallic materials to the flakes in the paint are aluminum, nickel, iron-based material and stainless steel. Stainless steel was used for the mass production in 2008. The magnetic permeability, which shows the sensitivity to magnetic force, was measured for the flakes made from individual materials (refer to Appendix 3). The results are shown in Fig. 15. The magnetic permeability is the highest in iron-based material and it becomes smaller in nickel followed by stainless steel. Meanwhile, aluminum is non-magnetic material.

In addition, the color of flakes is desirable when it is brighter and closer to an achromatic color. Accordingly, the hues of flakes are also measured. The measurement of hue was conducted based on CIE L\*a\*b\* color space defined by Commission Internationale de l'Éclairage (CIE)<sup>(3)</sup>. As

shown in Fig. 16, it is brighter when  $L^*$  is large and it is closer to achromatic color when the absolute values of  $a^*$  and  $b^*$  are small. Accordingly, in the selection, a larger value of  $L^*$  and small values of  $a^*$  and  $b^*$  are sought. The measurement results are shown in Fig. 15. The superiority order in relation to hue was like aluminum, iron-based material, stainless steel followed by nickel. Based on the measurement results on magnetic permeability and hue, the flake made from iron-based material was selected for our development.

| Flakes type                           | Magnetic permeability values ( $\mu$ ) | Color tones |       |       |
|---------------------------------------|----------------------------------------|-------------|-------|-------|
|                                       |                                        | $L^*$       | $a^*$ | $b^*$ |
| Aluminum (general metallic)           | 1.000                                  | 81.80       | -0.40 | 1.00  |
| Nickel                                | 1.780                                  | 69.14       | 0.53  | 4.44  |
| Stainless steel (conventional flakes) | 1.213                                  | 50.37       | 0.16  | 2.22  |
| Ferrous-material                      | 2.263                                  | 53.12       | -0.08 | -0.50 |

■ Sample preparation:

The flakes are ultrasonically cleaned in acetone bath. After that, they are dried and bottled in a container 6 mm. In diameter and 2.5 mm in height. The measurement is conducted to the container.

■ Magnetic permeability measurement

(1) Instrument:

- (1) Vibrating Sample Magnetometer
- (2) BHV-50
- (3) Riken Denshi Co., Ltd.

(2) Measurement condition:

Applied magnetic field: 10000 oersteds

■ Color measurement

(1) Instrument:

- (1) Name (generic): Spectrophotometer
- (2) Model: CM - 700 d
- (3) Make: KONIKA MINOLTA

(2) Measurement condition

- (1) Light source: D65 10
- (2) Detection mode: SCI

The color tones are measured using the base coat layer of paint resin with only flakes but without color pigments.

Fig. 15 Flakes with magnetic permeability and their color tones

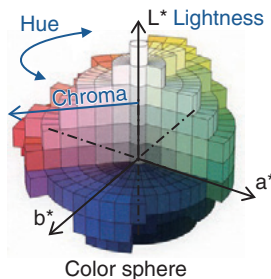


Fig. 16  $L^*$   $a^*$   $b^*$  color sphere

### 3.2.3. Understanding gloss loss generation mechanism and conception of measure to prevent it

As mentioned before, the ideal flake arrangement can be realized if the angles of the flakes can be fully changed to align with the lines of magnetic force before the paint is dried. However, if this is actually realized by applying some measure, a gloss loss occurs as a serious side effect in the central area of the decorative pattern. Gloss loss is a phenomenon with which the smoothness of the paint surface is lost and its glossiness is seriously deteriorated.

In Fig. 17, pictures that show appearances of gloss loss are presented as actual examples. A black and white striped pattern is irradiated with a light and the reflected light pattern is exposed onto the plate painted with a magnetically formed decorative paint. The picture shows the appearance of the plate in that condition. (a) shows the painted plate with gloss loss and (b) shows the one without it. The representations of the edges of the striped pattern in (a) are vague compared with (b). As shown in this example, gloss loss is a phenomenon with which the glossiness of a paint surface is seriously deteriorated. This gloss loss cannot be allowed in terms of the quality of paint appearance and it is inevitable to consider the measures to avoid that.

In the following, the reason why the gloss loss like this is caused is described. The magnetic sheet used for this painting has N pole on whole area of its one side and S pole on the other side. As illustrated in Fig. 18, the lines of magnetic force are radiated to spread around from the whole area of the surface. In the central area, the radiated lines of magnetic force are almost perpendicular to the sheet surface. Thus, the flakes in this area are eventually arranged almost perpendicular to the paint surface if they full move to change their orientations to align with the lines of magnetic force. (The simulation method that is provided the result shown in Fig. 18 is explained in Appendix 4.)

Consequently, the flakes stand perpendicular to the paint plane and get close to each other to form a chain connection to stick out of the interface of the paint layers. This generates the degradation of the paint smoothness resulting in a gloss loss (Fig. 19). Accordingly, for the central area of the decorative pattern, some strategic measure is necessary

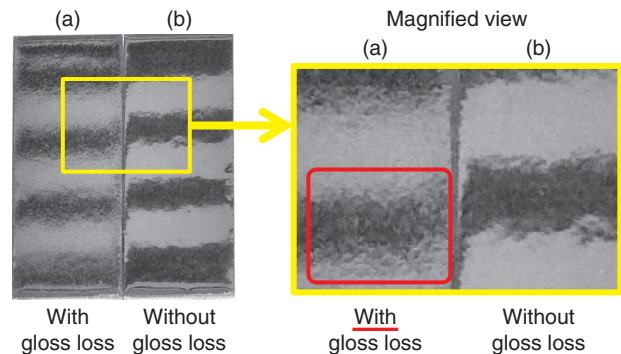


Fig. 17 Appearance of "gloss loss"

to prevent the angles of the flakes from getting angles close to perpendicular and make them stay within the range of the smaller angles.

### 3.2.4. Investigations to create method to overcome the obstacle

The movements of the flakes should be restrained so that their orientation angles stay within an angular range that is small enough to prevent a gloss loss. On the other hand, the flakes should be movable enough to yield a good plasticity. Accordingly, the allowable range of flake angles was tried to identify. To do so, the surfaces of the painted samples prepared in the process described in 2.2.3., which were made by changing the setup angles to a predetermined paralleled magnetic field, were observed to confirm the occurrences of a gloss loss.

In the upper row of Fig. 20, the photos of painted samples for individual angles that were taken in the same manner as taken for Fig. 17. From these photos, it can be

noticed that a significant gloss loss was generated in the sample that was made with the angle of 90 degrees to the paint layer. Moreover, a slight gloss loss is observed for the sample of 60 degrees. However, the sample of 45 degrees has no gloss loss. Consequently, it was confirmed that, if the flake slant angles are restrained within 45 degrees, the flakes would not stick out of the interface of the paint layers and the gloss loss can be prevented.

In the next step, a method to make the orientations of the flakes, which move to align with the lines of magnetic force, stay within 45 degrees to the paint surface was investigated. In the procedure of determining a paint formulation and a painting method to realize the desired flake angle arrangement, the investigation focus was set on the strength of magnetic force in the area where a gloss loss occurs. The graph in the lower row of Fig. 21 shows the results of the measurement on the strength of the magnetic field. The strength of the magnetic field, which is radiated as shown in the illustration in the upper row of the figure, was

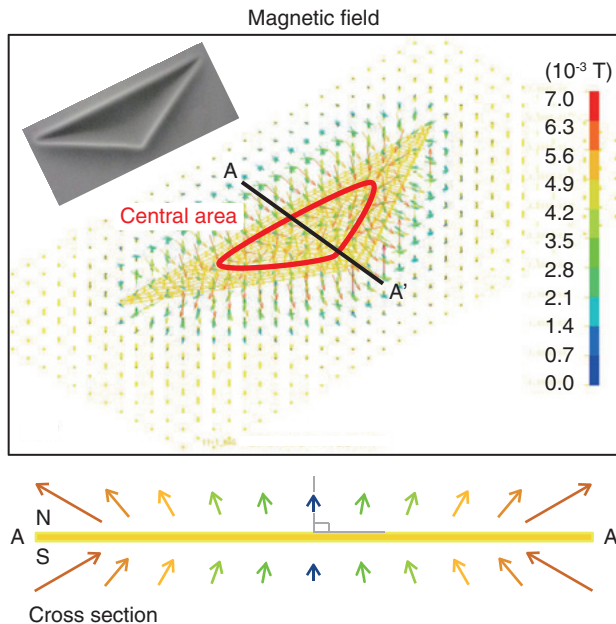


Fig. 18 Directions and strengths of magnetic fields from magnetic sheet

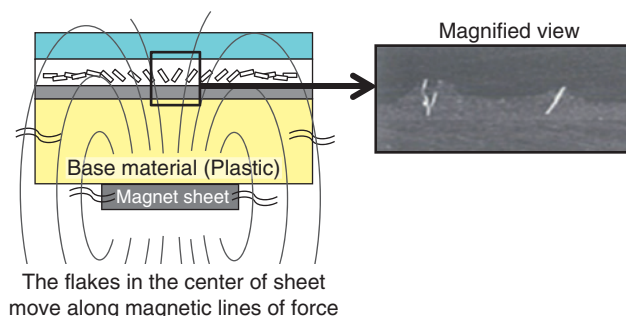


Fig. 19 Flake directions in area with gloss loss

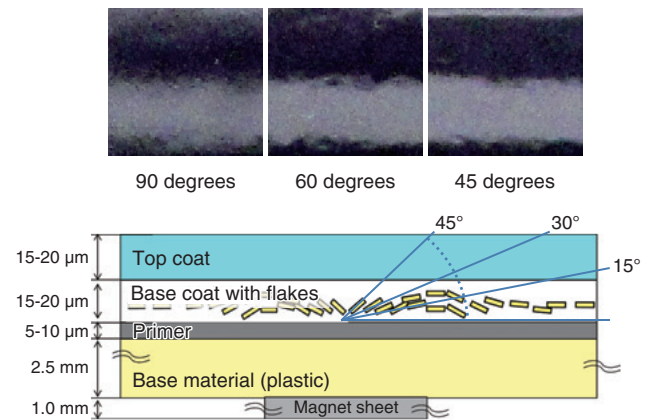
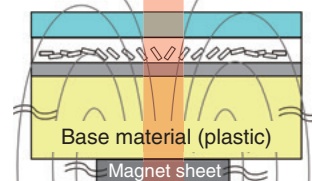


Fig. 20 Maximum flake angle to avoid gloss loss

Direction of the magnetic lines of force



Intensity of the magnetic lines of force

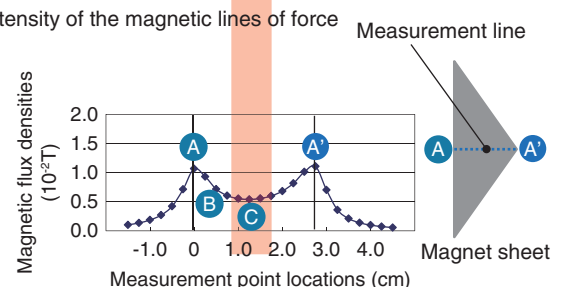


Fig. 21 Intensity of magnetic lines of force

measured at each position. The measurement was carried out through the line that is connecting point A and point A' on the magnet sheet. This data of the strength of magnetic force shown in the graph indicates that it is weak in the central area of the decorative pattern when it is compared to the area close to the perimeter. Based on this fact, it can be expected that it takes longer time for the flakes in the central area to move along the lines of magnetic force than for the flakes around the perimeter. A gloss loss occurs in the central area of the decorative pattern. That is to say, it occurs in the central area of the magnet sheet. Meanwhile, as the magnetic force is weak in the central area, it is assumed that it takes relatively long time for the flakes in this area to move to align their orientations to the angles close to 90 degrees. This delay was utilized to control the flake movements.

The measured regions and the respective final reaching angles are shown in Fig. 22. Three regions of A, B and C are picked up as representing portions. In each of the portions, there is a different flake angle distribution from the other portions in the magnetically formed decorative painting. The characteristics of each of them are described in the following. As shown in the upper right photo in Fig. 22, A is for the peripheral area, C is for the central area and B is for the area in between. As illustrated in the lower right drawing, the lines of magnetic force are emitted radially. Accordingly, the angles of the lines of magnetic force are getting larger along with the changes of positions from the peripheral area to the central area. Therefore, if the flakes moved to be completely aligned with the lines of magnetic force, the angle for the flakes in region A becomes 0 to 5 degrees, that of B is 45 degree and 90 degrees for region C. The angle that the flakes in a certain region are fully aligned with the line of magnetic force was defined as final reaching angle, or final angle (The table in Fig. 22).

A gloss loss occurs in region C that is the central area of the decorative pattern. As mentioned before, the angles for flake movements in region C should be restricted because it generates a gloss loss if they fully move to change the angles. On the contrary, the flakes in other regions,

especially those in region B, which are largely contributing to the manifestation of plasticity, should move fully to completely align with the lines of magnetic force to yield a high plasticity. As examined in the paragraph 3.2.4, in the central area, the strength of the magnetic force is weaker than that of the peripheral area and the flakes take more time to move. Therefore, the method was examined that makes the flakes in the peripheral region A and intermediate region B move in the full amounts while restricting the movable time for the flakes in central region C.

The relationship between the elapsed time after painting and the flake orientation angle is shown in the lower left graph in Fig. 22. The horizontal axis is for the time elapsed after the paint reaches the surface of the target part surface. The vertical axis is for the percentage of the flake angle to the final angle. Accordingly, reaching 100% of the final angle means that the angles of the flakes in a specific region, region A, B or C, fully reach the final angle of its individual region (e.g., 45 degrees for region B).

The vertical line shown in the middle of the graph in Fig. 22 indicates the completion timing of the painting process of the magnetically formed decorative painting. At this point, for the peripheral region A, the angle is almost reaching the final angle (0 degrees to 5 degrees). However, for region B and C, the angles have not reached the final angles when the painting process is finished. In other words, the painting has finished with a low plasticity. If the painting process time is extended so that the flake angles in region B, which has a significant influence on plasticity, reach the final angle (45 degrees), the flake angles in region C also reach almost their final angle (90 degrees) causing a gloss loss as a consequence. The paint formula dealt with in this graph is an equivalent condition as what we applied in the mass production in 2008. In reality, we prioritized the paint appearance free from a gloss loss and a high plasticity could not be achieved as a result. To achieve the target level of plasticity, the flakes in region B should be moved to reach their final angle before the paint process ends and, at the same time, the flake movements in region C should be terminated before they reach their final angle (at a smaller angle than 45 degrees). In short, regarding the flake movements, the manner shown in the graph (a) should be changed to the manner shown in the graph (b) in Fig. 23. To realize that, a paint formula design was investigated to move flakes fast and stop immediately.

To move the flakes fast, as it was mentioned earlier, application of a high magnetic permeability material to the flakes is one of the measures. On the other hand, the flake movement is largely influenced by the viscosity of the paint layer as well. Therefore, the control method of paint viscosity was also investigated as a measure to move flakes fast and stop immediately. Flake movements are under the control of paint viscosity. That is to say, flakes are movable only when the viscosity of the paint layer is smaller than some certain value. While the base coat was in wet condition, the behavior of the flakes moved

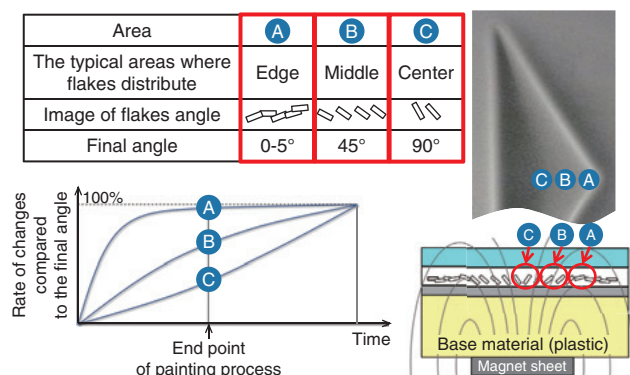


Fig. 22 Measurement points and final angles of flakes

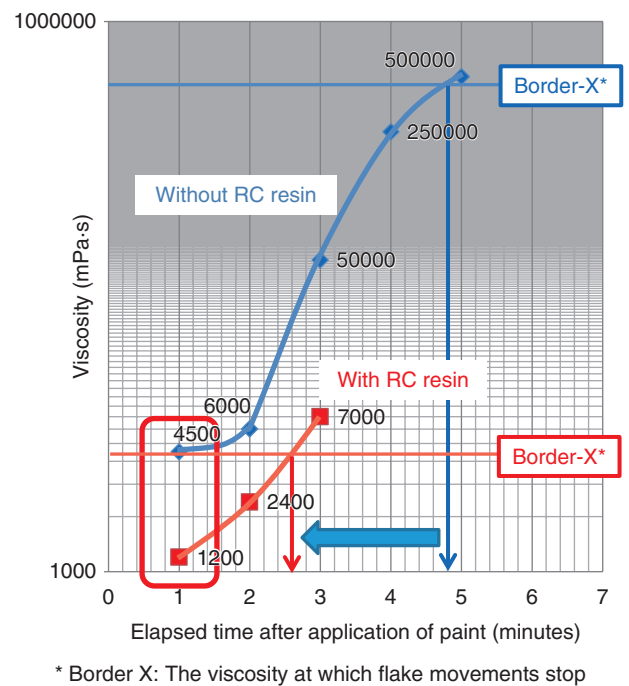
by an applied magnetic force was observed. Through this observation, a threshold value of the viscosity in the paint layer that distinguishes whether or not the flakes can move to align under the influences of lines of magnetic force was identified. This threshold viscosity value was defined as “Border-X viscosity.” The strategy was set to design the viscosity changes of the paint in the manner as described below. The viscosity stays still lower than the Border-X viscosity at the moment when the paint, which has been ejected from a spray gun, just lands on the surface of the painting object. Following to that, the viscosity increases immediately and reaches the Border-X viscosity or beyond. To realize this steep increase of the viscosity, a high molecular weight resin (rheology control resin or RC resin), the molecular weight of which is more than a hundred thousand was used. When a RC resin is added, the viscosity of paint before spraying is also increased and it generally causes a difficulty in maintaining the smoothness of the paint surface after painting. To cope with this difficulty, the dilution rate of the thinner was also increased. This made the paint viscosity decreased just after the spraying contributing to realize quick movements of the flakes as a consequence (Table 4).

The graph in Fig. 24 shows the viscosity variations of the paint comparing the paint added with a high molecular weight resin and the one without it. The horizontal axis is for elapsed time and the vertical is for viscosity in logarithmic scale. The red line in the graph shows the data for the paint developed this time, in comparison with the one without adding the high molecular weight resin (shown by the blue line) that is in almost equivalent condition as the paint developed for the mass production in 2008. It can be understood that the viscosity value of Border-X, which is the viscosity to make the flakes unmovable, goes down significantly by adding the high molecular weight resin. Moreover, by increasing the dilution rate, the initial viscosity of the developed paint was also decreased to be smaller than before. Through these results, the flakes were allowed to move quickly but the time until the flake movements were halted was shortened after the paint application. By implementing those methods, a paint

Table 4 Purposes and measures of viscosity adjustment

| Required effects on flake | Viscosity requirements                                                        | Method                                            |
|---------------------------|-------------------------------------------------------------------------------|---------------------------------------------------|
| <b>Move fast</b>          | The initial viscosity should be low.                                          | Increasing the <b>dilution ratio</b> of the paint |
| <b>Stop immediately</b>   | The viscosity should quickly reach to the level where the flakes stop moving. | Adding the <b>high-molecular-weight resin*</b>    |

\* High-molecular-weight resin (RC resin):  
Material used for rheology control that stops movements of flakes in paints



\* Border X: The viscosity at which flake movements stop

Fig. 24 Viscosity increases of paint with and without RC resin

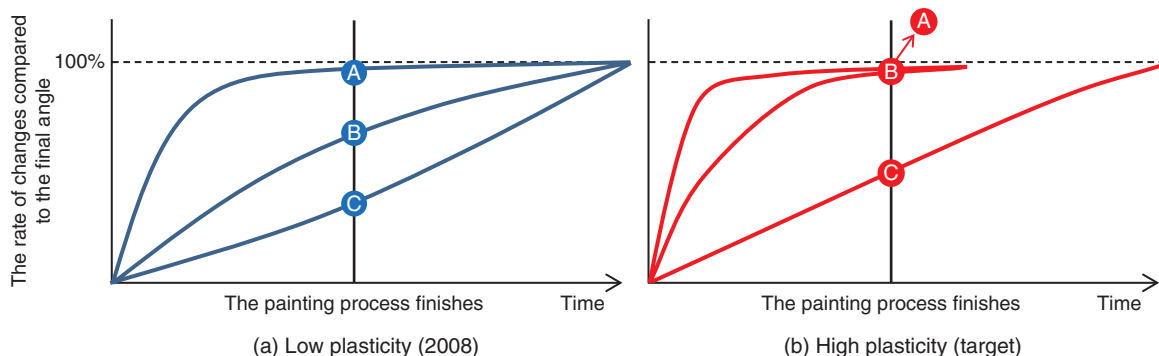


Fig. 23 Flake movements of fast move and immediate stop

formula that satisfied the target viscosity characteristics was successfully designed. The measurement method is explained in Appendix 5.

Based on this paint formula, test paintings were conducted with different constituent ratios of the high molecular weight resin and those of the thinner to compare the performances of the paint layer and the workability of them. With those results, the paint specification to be applied to the mass production was decided.

## 4. Results

### 4.1. Conditions for Deciding Paint Formula

For investigating the paint specification, four kinds of paints were prepared with different constituent ratios of the high molecular weight resin that help the flakes to stop their movement promptly. The variations of the constituent ratio were 20%, 30%, 40% and 50%. The paint that contains no high molecular weight resin was also prepared for a comparative evaluation purpose. This formula without high molecular resin is almost the same formula applied for the mass production in 2008. However, in this particular evaluation test, the high magnetic permeability flakes were used for this paint as well, like the other paints to be evaluated, to conduct the comparative evaluation effectively. These prepared paints were painted while the magnet sheet of the triangular shape, which was defined as the base decorative pattern, was attached to the rear side. Following to these paint samples' preparations, comparative evaluations on basic paint coating performances, paint appearance and paint workability were conducted to finalize the specification selection. The workability in this particular evaluation means whether or not the necessary paint layer thickness can be obtained through the production process supposed to be deployed. The evaporation speed of the thinner was decided based on the settings of temperature and humidity for the painting booth used in the factory in Vietnam where the actual mass production was planned. Moreover, the non-volatizing material ratio after dilution by thinner (NV%) was also decided based on the evaluation results yielded using those formulae. For example, when the dilution ratio is increased, the NV% is decreased. For the paint that contain 0% of the high molecular weight resin (RC resin), the NV% was set at High. For 20% of that, it was set at Middle, and they were set at Low for other percentages.

### 4.2. Detailed Descriptions on Results

The test results are shown in Fig. 25. The photos show the individual appearances of the painted samples of the evaluation formulae 0 to 4. It is observed that there is a correlation between the constituent ratio of the high molecular weight resin and the plasticity. When the constituent ratio of the high molecular weight resin is high, the plasticity is high presenting a favorable appearance. The plasticity was rated based on the evaluation method described in the paragraph 2.3.2. The levels of plasticity

were rated as equal or above plasticity level 3 for all the evaluated paints containing the high molecular weight resin (specifications from 1 to 4). In any paints of evaluated specifications, there was no gloss loss occurred in either of the decorative pattern area or the area without it.

Furthermore, performances for the general requirements for a paint layer, e.g. adhesion performance, were also confirmed. The results were obtained that indicated no defect and satisfied all the paint requirements for all of the specifications. The details on evaluation methods for individual tests are presented in Appendix 6.

Lastly, touching on the workability, the results showed that it gets harder to obtain the necessary paint layer thickness through the painting line in the mass production process when a larger amount of the high molecular weight resin is added. Consequently, it was finally judged that the specification that contain approximately 30% of the high molecular weight resin, which was defined as specification number 2, was the allowable limit within the permissible performance range (refer to the lower most row in Fig. 25). Based on those results, to determine the final specification for mass production, the appearance and the paint workability in the actual mass production line were further investigated to conclude the judgment.

### 4.3. Deciding Specification for Mass Production

The judgment process of the mass production specification, taking the requirements for the appearance and the workability into account, is described below. As mentioned in the paragraph 3.2.4., as the viscosity is increased by the addition of the high molecular weight resin, the paint viscosity should be set low by increasing the dilution ratio of the thinner to maintain the smoothness of the paint surface. When the dilution ratio of the thinner is increased, the ratio of the non-volatizing material (NV%) that constitutes the paint layer finally formed goes down. Thus, the required concealing thickness of the paint layer (15 to 17  $\mu\text{m}$ ) cannot be obtained by one paint spraying process.

Moreover, under the mass production process condition, the amount of the paint to be sprayed at a time has a limit. The number of times for repetitive painting is generally restrained within two or three in a mass production process. Accordingly, in light of the paint process requirement, it is required to form the necessary concealing thickness of the paint layer within these numbers of times of spraying.

The number of times of painting conditioned in the manufacturing line was three in Vietnam factory, which was planned for the mass production factory for the vehicle. Accordingly, it was required to determine the dilution rate so that the necessary paint layer thickness could be obtained (which was 15 to 20% when defined by NV%) within the number of repetitive paint sprayings. By adding larger amount of the high molecular weight resin, the plasticity can be more enhanced. However, the limitation of the setting for the dilution rate of the thinner, which arises from the restrictions in the mass production process mentioned

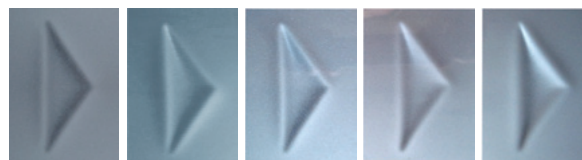
above, should be taken into account as well. Consequently, the constituent ratio of the high molecular weight resin was determined so as to meet the requirement for the thickness of the formed paint layer.

Following these considerations, the constituent ratio of the high molecular weight resin to the amount of base resin was determined as 20 to 25% for the finalized paint design to be used in mass production. Finally, the specification number 1, which is one of the options meeting the overall evaluation criteria shown in Fig. 25, was selected as the specification for mass production.

The practical test painting was conducted at the

production line in Vietnam factory using the developed paint applying the conditions described above. As a result, it was confirmed that a good plasticity was achieved without any issues on its workability as well. By applying the same test painting process, painting was conducted using the triangular magnet sheet that was defined as the base shape for plasticity measurement mentioned before. It was followed by the measurement of the variation of the light intensity to the detecting angle, and it was verified that the target plasticity of level 3 had been achieved. The developed paint was applied in the mass production in Vietnam (Fig. 26).

|                      | Specification No.                                                          |                                         | 0         | 1         | 2         | 3         | 4         |
|----------------------|----------------------------------------------------------------------------|-----------------------------------------|-----------|-----------|-----------|-----------|-----------|
|                      | Addition of RC resin                                                       |                                         | None      | Applied   | Applied   | Applied   | Applied   |
| Paint specifications | Contained ratio of RC resin* <sup>1</sup>                                  |                                         | 0.0%      | 20.0%     | 32.0%     | 40.0%     | 50.0%     |
|                      | Contained flake ratio (PHR)* <sup>1</sup>                                  |                                         | 15 PHR    | 15 PHR    | 15 PHR    | 15 PHR    | 15 PHR    |
|                      | Non-volatizing material ratio after diluted by thinner (NV%)* <sup>2</sup> |                                         | HIGH      | MIDDLE    | LOW       | LOW       | LOW       |
| Results Appearance   | Plasticity level (Inclination of approximation line)                       |                                         | 2 (-1.22) | 3 (-0.73) | 3 (-0.71) | 4 (-0.38) | 4 (-0.28) |
|                      | Initial gloss value* <sup>3</sup>                                          | The area of design pattern              | 95        | 95        | 96        | 94        | 94        |
|                      |                                                                            | The area without pattern                | 95        | 97        | 98        | 97        | 96        |
| Results Performance  | Initial adhesion performance* <sup>4</sup>                                 |                                         | Good      | Good      | Good      | Good      | Good      |
|                      | Water resistance* <sup>4</sup>                                             |                                         | Good      | Good      | Good      | Good      | Good      |
|                      | Durability against accelerated weather stress* <sup>5</sup>                | Non-discoloring* <sup>6</sup>           | Good      | Good      | Good      | Good      | Good      |
|                      |                                                                            | Gloss* <sup>7</sup>                     | Good      | Good      | Good      | Good      | Good      |
|                      |                                                                            | Adhesion performance* <sup>4</sup>      | Good      | Good      | Good      | Good      | Good      |
|                      |                                                                            | Disorders of paint layers* <sup>8</sup> | None      | None      | None      | None      | None      |
| Results Paintability | Thickness of paint layers* <sup>7,9</sup>                                  |                                         | Good      | Good      | Fair      | Poor      | Very poor |



\*1 Ratio to the base resin

\*2 The thinner is added until the viscosity reaches 13 second at 26 degrees in Celsius using Iwata-cup.

\*3 Measurement is carried out using gloss meter and the detecting angle is set at 60 degrees.  
(Equipment: Gloss meter, Micro tri gloss, BYK Additives & Instruments)

\*4 "Good" denotes that none of the tiles are peeled off.

\*5 Results are evaluated for the areas both with and without design patterns and the evaluation results shown in the table are the total performances.

\*6 Color difference  $\Delta E$  is measured using Spectrophotometer.

"Good" denotes  $\Delta E = 2$  or less.

(Equipment: Spectrophotometer, CR-300, MINOLTA)

\*7 "Good" denotes satisfying the requirement,

"Fair" denotes barely satisfying the requirement and

"Poor" denotes unsatisfying the requirement.

\*8 Disorders include checkings, cracks and blister. Those are visually observed.

\*9 Whether or not the total thickness of sprayed base coat paint reaches the required thickness for hiding the primer layer under the paint process in actual manufacturing.

Fig. 25 Test results



Fig. 26 Final product with plastic coverings painted by magnetically formed decorative painting

## 5. Conclusions

Paint was developed to enhance the attractiveness of the outer look of plastic coverings in motorcycles. For that purpose, a magnetically formed decorative painting was employed and the developments of the paint and the painting method were conducted aiming at an enhancement of the plasticity (three-dimensionality) represented by a decorative pattern compared to the existing painting method. Through the process of identifying the obstacles and solving the issues experienced in this development, the knowledge described in the following was acquired.

- (1) The target plasticity level was numerically defined based on the numerical scale created to describe the degree of light intensity variation that significantly involves in the degree of plasticity.
- (2) The mechanism through which plasticity is generated was investigated and the flake orientation arrangement in the paint layer was clarified to practically realize the target plasticity.

In the process of the concrete development of the paint and the painting method, the effectiveness was verified for the methods described below.

### 1. Paint

- (1) As for the flake material, iron-based material is the best fitted because of its high magnetic permeability (the magnetic permeability of 2.2), high brightness ( $L^*$  value of 50 or above) and closeness to an achromatic color.
- (2) The characteristic of the paint viscosity is designed so that the flake movements stop within a short period by using the high molecular weight resin (RC resin, with the molecular weight of a hundred thousand or above) to fully increase the viscosity in a short time after the paint application.

### 2. Painting method

- (1) The target scheme of the viscosity changes, which is designed to move the flakes promptly and stop them within a short period, was determined. Based on that scheme, the addition amount of the high molecular-weight resin was determined. The constituent ratio was decided from 20% to 25% or around. These were fixed with consideration of the restrictions that arise from the existing painting procedures in a factory.
- (2) Non-volatizing material ratio (NV%) is set at from 15% to 20% or around by adjusting the dilution rate of the thinner.

By combining the methods described above, a magnetically formed decorative painting method was successfully realizing the target plasticity that is higher than the one by existing method.

Through the development of this technology, motorcycles with enhanced attractiveness in the vehicle exterior design were able to be offered to the customers.

## Acknowledgments

We would like to show our special thanks to the people listed below for their efforts to contribute to our study.

Akinori Kotera, Thai Kansai Paint Co., Ltd

Hideaki Katsuta, Kansai Paint Co., Ltd

## References

- (1) JP, 2857276 (1999)
- (2) JP, 2868948 (1999)
- (3) <http://www.konicaminolta.jp/instruments/knowledge/color/part1/07.html>

## Appendix 1

### <Light intensity>

There are many units to indicate some value of light depending on how the value is defined. The measurement target in our study is a surface of painted object, and is not generating a light by itself. We considered the most appropriate physical expression to be used is luminosity (= luminous intensity) under a condition of exposure with an external light.

However, some of the apparatuses we used in our experiments were not employing SI units. The non-standardized units are still viable for particular purposes of measurement. The precise calibrations are needed if they are to be converted into SI units. Those calibrations are not practical in many cases and we would get no further information about the concerned matter even though we conducted the calibration.

Under the study goal we set, most of the measurements were conducted to know the degree of plasticity. Therefore, basically, the absolute value of an intensity of a light is not a matter of concern. The purposes of measurements are to

know the variations of intensity of a light depending on the positions of measurement points and/or the changes of the measurement angle.

Based on this background, when the measurement values were yielded in the unit of “luminosity”, we applied that unit. If the measured data are expressed in other units, just like the measured values by a variable-angular photometer, we used “light intensity” instead of using some standardized expression. In the descriptions appeared in our paper, we used “luminosity” when it was clearly measured or defined so, and we used “light intensity” when we were referring to a strength of light in general.

As mentioned before, when it is considered with the intension of this paper, in which relative value is the subject to be investigated, using luminosity and light intensity are practically the same.

## Appendix 2

### <Test piece fabrication method>

- (1) Three kinds of thinners were prepared beforehand.
  - (a) Thinner with a composition mainly using solvents with boiling points of 100 to 130 degrees Celsius
  - (b) Thinner with a composition mainly using solvents with boiling points of 140 to 180 degrees Celsius
  - (c) Thinner with a composition using a solvent with a boiling point over 180 degrees Celsius
- (2) The thinners were mixed to have five different constituent ratios to realize five different volatilization performances.
- (3) A base paint resin and a hardener were mixed in a predetermined constituent ratio and combined with different thinners described above.
- (4) Thus prepared five different paints were applied to ABS resin plates with the standardized magnet sheets attached to them.

## Appendix 3

### <Magnetic permeability>

Magnetic permeability is the degree of magnetization that a material obtains in response to an applied magnetic field. It also shows the ability of a material to support the formation of a magnetic field within itself.

In our study context, the larger the permeability is the easier the flakes are oriented to the direction of the magnetic field.

Magnetic permeability is usually defined as a property inherent to individual material itself. However, in our applications, the shapes of the metal are processed into flakes and the effective permeability value may be different from that of the un-processed original material.

The permeability values shown in Fig. 15 are the values in flake forms.

## Appendix 4

### <Simulation method>

Directions and strengths of the magnetic field are simulated by software application (ELF MAGIC ver. 3.40, Elf Co., Ltd.) providing the inherent residual magnetic flux density of the sheet material (228.0 mT) and its shape with the dimensions. The comparison between the simulation results and measured values is shown in Table 5 and the representations by graphs are shown in Fig. 27.

The simulation results were verified at some points with actual measurement data as shown below.

Table 5 Comparison of measurement value and simulation result

| A-A' (mm) | Actual measurement ( $10^{-3}\text{T}$ ) | Simulation ( $10^{-3}\text{T}$ ) | Measurement value divided by simulation result |
|-----------|------------------------------------------|----------------------------------|------------------------------------------------|
| 0.0       | 1.55                                     | 1.66                             | 93.37%                                         |
| 2.5       | 3.89                                     | 3.99                             | 97.49%                                         |
| 5.0       | 5.09                                     | 4.84                             | 105.17%                                        |
| 7.5       | 5.25                                     | 4.91                             | 106.92%                                        |
| 10.0      | 5.16                                     | 4.83                             | 106.83%                                        |
| 12.5      | 5.13                                     | 4.81                             | 106.65%                                        |
| 15.0      | 5.22                                     | 4.88                             | 106.97%                                        |
| 17.5      | 5.41                                     | 5.03                             | 107.55%                                        |
| 20.0      | 5.65                                     | 5.20                             | 108.65%                                        |
| 22.5      | 5.67                                     | 5.17                             | 109.67%                                        |
| 25.0      | 4.92                                     | 4.41                             | 111.56%                                        |
| 27.5      | 2.65                                     | 2.34                             | 113.25%                                        |
| 30.0      | 0.00                                     | -0.01                            | 0.00%                                          |

Simulation software : ELF MAGIC ver.3.40, ELF Co., Ltd.

Measurement equipment: Magnetic flux density meter (Tesla Meter, TM-601, KANETEC Co., Ltd.)

- Measurement points and conditions

- (1) The positions located on the A-A' line at Fig. 21 and the height is 5.0 millimeters.
- (2) The magnetic flux densities in vertical direction were measured.
- (3) On the side of North Pole of the magnet sheet polarity.

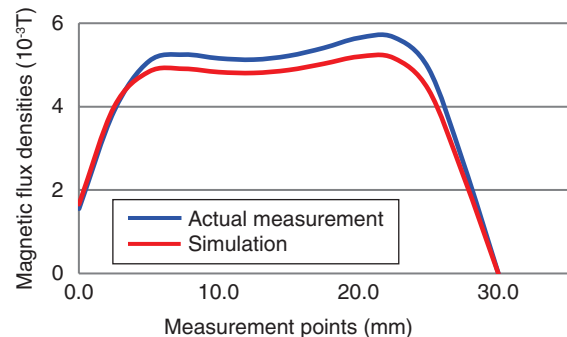


Fig. 27 Comparison of measurement value and simulation result

## Appendix 5

### <Measurement method of viscosity>

Step 1: Making the reference graph between non-volatilizing substance constituent ratio and viscosity

- (1) Base resin, hardener and thinner are mixed together in a standard constituent ratio.
- (2) The mixed paint material is put on a platter and the solvent is volatilized while stirring at room temperature.
- (3) Pick up samples several times after the increase of the viscosity is visually observed.
- (4) Non-volatilizing substance constituent ratios and viscosities are measured.
- (5) Based on these measured values, the graph showing the relationship between a non-volatilizing substance constituent ratio of the paint and its corresponding viscosity is created.
- (6) This reference graph is used in the actual viscosity measurement, which is described below, converting plotted data of non-volatilizing substance constituent ratios into viscosities.

(Measurement equipment and conditions)

- (a) Viscosity
  - Viscometer: LVDV-1+, Brookfield Engineering Laboratories
  - Spindle/rotational speed: #4/60 rpm
  - Temperature: 26 degrees Celsius
- (b) Non-volatizing substance constituent ratio
  - Two grams of a sample is put on a tin plate.
  - The sample is heated at 110 degrees Celsius for 3 hours.
  - The weight after heating is measured and used for the calculation.

Step 2: Measuring a non-volatilizing substance constituent ratio and converting into the viscosity value

- (1) A couple of sheets of aluminum foil cut to a predetermined size are attached to the target part, and a prepared paint is sprayed onto the part.
- (2) Peel off a sheet of aluminum foil and fold it immediately to seal it up after the predetermined time; one, two and three minutes, after the spraying.
- (3) Measure the weight of the sheet of foil while keeping folded.
- (4) Unfold the sheet of foil and leave it for a predetermined time and measure the weight again.
- (5) The weight difference between before and after drying is used to calculate the non-volatilized substance constituent ratio in percent.
- (6) Using the conversion graph we have got in Step 1, the yielded value is converted into the corresponding viscosity value.

## Appendix 6

### <Descriptions of individual evaluation tests>

#### 1. Plasticity

The plasticity of magnetically formed design patterns

was evaluated for the sample plates painted in different conditions. A variable-angular photometer was used for the measurement and the results were compared to the plasticity scale we defined.

#### 2. Adhesion performance, water resistance and durability against weather stress.

We conducted the evaluation of initial adhesion performance, water resistance and durability against weather stress on each painted sample plate by applying the test methods described below.

##### (1) Initial adhesion performance:

We applied scratched lines with a box cutter so as for the grooves to reach the base material of the paint target part under the paint layers for both the area of the design pattern and the area without pattern on the sample plate of the individual paint condition. Thus we formed 100 tiles on the paint surface with square shapes of 1 mm by 1 mm.

After that, adhesive cellophane tape ("Sellotape" under British Trade Mark) was firmly applied to the paint surface with pressure and the numbers of the remaining tiles were counted for the area of design pattern and the non-patterned area after applying abrupt peeling of the tape off the surface at the temperature of 20 degrees in Celsius.

##### (2) Water resistance

Each painted sample plate was immersed in a water bath at 40 degree Celsius and kept for 10 days. After that, the sample plates were pulled out and dried. The adhesive performance test procedures were applied in the same manner as mentioned earlier for the initial adhesion test.

##### (3) Durability against accelerated weather stress

Each painted sample plate was exposed to light, water and heat in a sunshine weather meter for 85 hours and immersed in a water bath at 40 degrees Celsius. After that, it was pulled out from the bath and dried. The same test procedures as the initial adhesion performance test was applied to conduct evaluations by counting the remaining tiles for the area with design patterns and without them following the same manner as described before.

This series of procedures was defined as one test cycle and we kept doing the evaluation until it reaches to 10 cycles.

### ■ Author ■



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