

Development of Waterborne Primer Applicable to Different Plastics in Motorcycles

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ABSTRACT

Most of the paint materials currently used for motorcycles contain a large amount of Volatile Organic Compounds. Volatile Organic Compounds are environmental load substances, and there is a strong demand for reducing their emissions in recent years. Many of a motorcycle's exterior parts are made of ABS plastics or PA plastics. These two plastic materials have different film adhesion mechanisms and adhesion strengths. Therefore it was necessary to use different conductive primers and it was one of the factors that caused a loss of time and materials in the painting processes. We challenged those two objectives, i.e., the reduction of Volatile Organic Compounds and the common use of the same conductive primer for different parts materials, by combining two kinds of resins originally designed individually, i.e., urethane resins with carboxylic acid groups and acrylic resins with amide groups, which have different properties. Many of the plastic parts used in motorcycles are painted manually because they have difficult areas to be painted by automated painting machines. Thus, the viscosity was adjusted to satisfy both the controllability of paint sagging and the surface smoothness to maintain the efficiency of paint workers' operations by using a thixotropic rheology control agent.

1. Introduction

1.1. Adoption of Waterborne Paint to Reduce VOCs

Recently, public concerns for environmental issues have been significantly growing. Chemical substances that are hazardous to the environment and/or health have been recognized as environmental load substances, and are now under regulations. Volatile Organic Compounds (VOCs) are a variety of those environmental load substances and are contained in the materials used in paints as well. "VOCs" is a general term for organic compounds that easily evaporate and remain as a gaseous body in the atmosphere, and VOCs are considered as a group of the substances that cause photochemical smog through photochemical reactions in the atmosphere. In some countries, regulations on VOCs have been enacted such as the Clean Air Act in the United States, TA-Luft in Germany and the Environmental Protection Act in the United Kingdom. In Japan, the Air Pollution Control Act was revised in April 2006 to include VOC regulations. This prompted the Japan Automobile Manufacturers Association (JAMA) to set a stricter target, aiming to reduce VOCs by 40%, compared to 2000, until 2010. Japanese automobile manufacturers have developed various technologies^{(1), (2)} to meet this target. VOCs are contained in the organic solvents of painting materials and discharged during the painting

processes in the automobile production lines. Since earlier times before JAMA set that target, great efforts had been made in Honda factories towards the improvement in painting efficiency, the retrieval of paint thinner and the adoption of high-solid-type solventborne paint. However, more efforts were needed to meet JAMA's target of a 40% reduction. Therefore, we had made further steps to adopt waterborne paint to achieve even larger reduction of VOC emissions.

1.2. Painting Materials to Be Changed into Waterborne Materials

The parts of a motorcycle that are painted are metal tanks, metal frames and plastic exterior parts such as cowls. Figure 1 shows proportions of VOC emissions per square meter from each part category in Honda's Kumamoto Factory. As can be seen from the graph, the greatest VOC emissions occur in the painting of the plastic exterior parts. To determine the details on the sources of the emissions, the VOC emissions for each layer of the painting materials were examined. The results are shown in Fig. 2. The paint layer structure has two layers composed of a primer and a top coat, which consists of a base coat and a clear coat, to give colored appearances. The primer is the main cause of such high VOC emissions generated during the painting process of the exterior parts. The chart in Fig. 2 shows that the primer emits

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more VOCs than the base coat and clear coat. This is because the primer is a one-composite material and it cannot be produced as a high-solid type. Based on those circumstances, it was expected that a large reduction of VOCs could be achievable if the solvent-borne primers were replaced with waterborne primers, and a reduction of VOC rate in primers was realized from 70% to a few percentage points.

This expectation motivated us to make attempts to alter the solventborne primers currently used with the newly developed waterborne primer applicable to the plastic exterior parts.

1.3. Functions of Primers and Creation of One Common Primer

The primer is a film applied between a part and its top coat film used for a colored appearance. Its function is to apply conductivity for electrostatic spraying and to facilitate the adhesion between the top coat film and the parts.

The transfer efficiency in painting can be significantly improved by using the electrostatic spraying method in which large amounts of paint material are carried on to the parts to be painted with the help of electrostatic forces generated by

electrical fields that are created by voltage applied between the paint spray gun and the parts. Non-electrostatic spraying has low transfer efficiency, because a large amount of the paint does not reach the target parts (Fig. 3). To apply the electrostatic spraying method, the target parts to be painted should have electrical conductivity, which is why conductive primers should be applied to plastic parts without conductivity when the top coat paint is electrostatically spray-painted.

Adhesion strength to a paint film varies from one plastic material to another. When the adhesion of the plastic is low, a primer with good adhesion characteristics to the plastic needs to be applied.

Figure 4 shows examples of plastic exterior parts of a motorcycle. Three different types of plastics are used for the

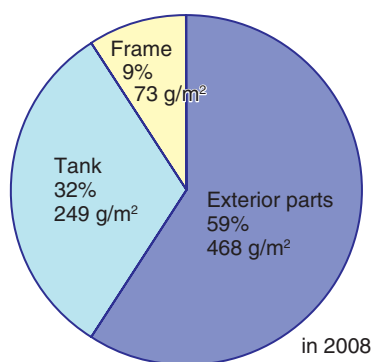


Fig. 1 Proportions of VOC emissions from each part category

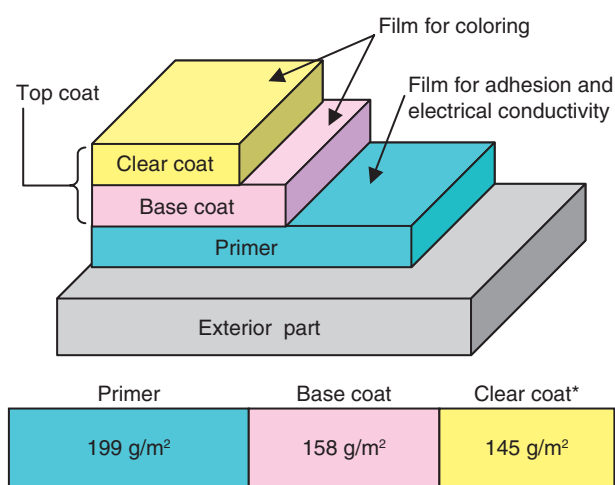


Fig. 2 Paint composition on exterior parts and VOC emission amount

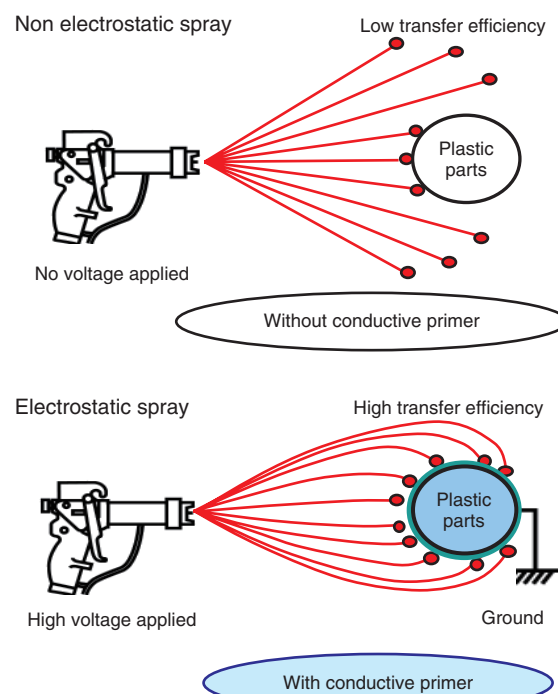


Fig. 3 Difference between non-electrostatic spray and electrostatic spray

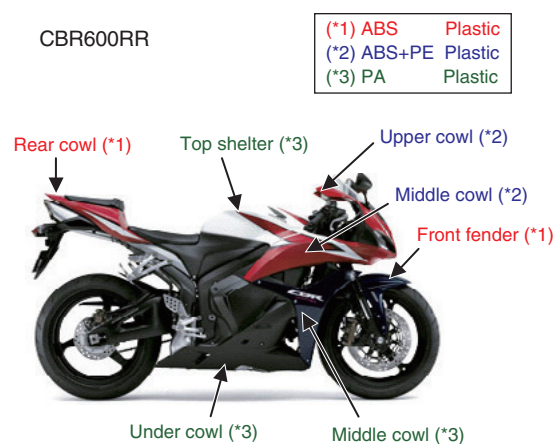


Fig. 4 Plastic exterior parts of motorcycle

Table 1 Plastic type and features for applications

Plastic type	Features for applications
ABS	Easiness for painting
ABS+PE	Resistance against chemical agents
PA	Heat resistance

outer coverings of a motorcycle. Table 1 shows the features of the plastics to fulfill the requirements in motorcycle applications. The roles of the primers are outlined as follows. In the case of ABS and ABS with PE (Polyethylene) plastic (hereafter ABS+PE), the primer is used only to apply conductivity for electrostatic spraying, because two-package-type urethane acrylic paint adheres well to these plastics without primer.

In the case of PA plastic, on the other hand, the film does not adhere well. Therefore, a primer is required not only to provide conductivity, but also to ensure adhesion of the film to the parts. Thus, in this case, the primer plays the major role in preventing the film from peeling.

ABS and PA have different mechanisms of adhesion to primers and two different primers have to be separately used. This imposes on the necessity of management of time and material losses during the painting processes in our factories. These situations motivated us to develop a waterborne primer that can be used on both ABS and PA plastics.

Keeping the two objectives mentioned above in mind, we developed a waterborne conductive primer that could be used on different plastic materials of motorcycles, in order to reduce VOCs and simplify the painting process.

2. Requirements in Development

The requirements for our development of a waterborne conductive primer that could be used on different plastic materials were as follows:

- (1) Organic solvent proportion (to whole primer quantity): Less than 3% (which is the amount to satisfy VOC emissions regulations)
- (2) Surface electrical resistance: No more than 0.05 MΩcm (which is the value that fulfills the transfer efficiency requirement for electrostatic spraying)
- (3) Substrate: ABS, ABS+PE and PA can be applied
- (4) Paint film performances (initial adhesion, water resistance, humidity resistance, etc.): Equivalent to or better than current product
- (5) Painting properties (sagging prevention management, surface smoothness of wet film, etc.): Equivalent to or better than current product
- (6) Surface smoothness of dry film (LW, SW): Equivalent to or better than current product

3. Issues and Technical Measures

3.1. Adhesion to ABS and PA and Resin Design

ABS can be made to adhere to the paint film without

difficulty by adding functional groups with polarity to the primer resins, because ABS contains nitrile groups with high polarity. Meanwhile, PA can not easily be made adhesive because it has less polarity with its crystallized structure. Therefore, regarding PA, the binding force for adhesion is mainly created by the intermolecular force of the alkyl chains between the primer resin and PA and by hydrogen bonding between the polar functional groups of the primer resin and the amide groups of PA. Moreover, in motorcycle applications, plastic parts are used even in high-temperature locations such as in the vicinity of an engine or an exhaust pipe. For those parts used under high temperatures, PA is usually selected because of its high melting point and being reinforced with glass filler. However, where the glass filler appears on the surface of the plastic (Fig. 5) the adhesion between the primer film and the plastic is further reduced.

Regarding adhesion strength between the top coat film and primer on ABS or PA, it does not become an issue because of the actions of polar functional groups contained both in the resin of the top coat film and in the resin of the primer film.

Because of these differences in adhesion mechanisms to the primer, a primer resin must be individually designed for each plastic. In those circumstances, we tried to select the appropriate principal chains and side chains in resins that adhered to ABS and PA and examine the suitable combination and the correct composition ratio. Table 2 shows the resins selected and their adhesion mechanisms. Figure 6 illustrates the adhesion mechanisms.

3.2. Decrease of Film Performance Due to Remaining Water and Increment of Solid Content Ratio*

A film of two-package-type urethane acrylic paint is formed by the reaction between the hydroxyl groups in the acrylic resin, the base resin, and the isocyanate groups in the isocyanate resin, the hardening agent, forming urethane bonds and creating a cross-linking reaction between them (Fig. 7). The hardening agent in the top coat paint also reacts with the hydroxyl groups in the primer resin, creating adhesion between the top coat film and the primer film.

Waterborne primer contains water as the solvent, and since water is less volatile, more water remains in the primer



Fig. 5 Glass fillers appeared on surface of PA

Table 2 Resin type and adhesion mechanisms

Resin type		Target of adhesion	Adhesion mechanisms
Principal chain	Urethane emulsion	ABS PA	Dipolar interactions and hydrogen bonds between: (1) ABS; urethane bonds of urethane resin and nitrile groups of ABS (2) PA; urethane bonds of urethane resin and amide bond of PA
	Acrylic emulsion	PA	Intermolecular force of alkyl chains between acrylic resin and PA
Function group in side chain	Carboxylic acid groups	ABS PA	Dipolar interactions and hydrogen bonds between: (1) ABS; carboxylic acid groups and nitrile groups of ABS (2) PA; carboxylic acid groups and amide groups of PA
	Sulfonic acid groups	ABS PA	Dipolar interactions and hydrogen bonds between: (1) ABS; sulfonic acid groups and nitrile groups of ABS (2) PA; sulfonic acid groups and amide groups of PA
	Amide groups	PA	Dipolar interactions and hydrogen bonds between amide groups and amide groups of PA

film for a long time after it has been applied. If the top coat paint is applied while the primer still contains a large amount of water, the water from the primer will seep into the top coat paint. As the isocyanate groups in the hardening

agent preferentially react with water than with the hydroxyl groups in the base resin, this interferes with the cross-linking reactions between the base resin and hardening agent, resulting in softening of the top coat film and the poor adhesion between the top coat film and the primer film (Fig. 8). Additionally bake-finishing after painting over primer containing water causes such deterioration in appearance as blisters in the film caused by vaporized water.

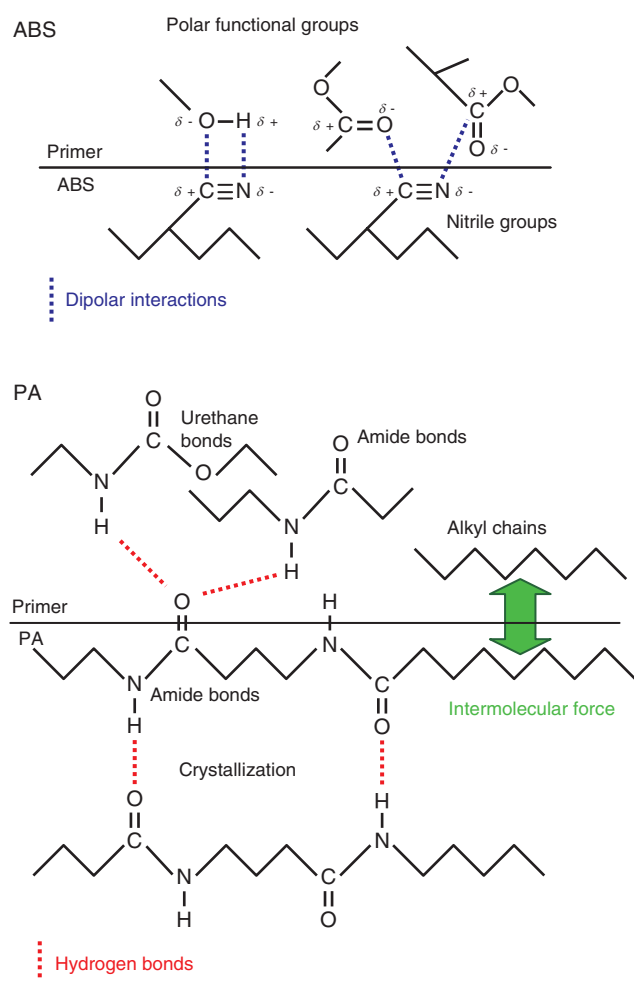


Fig. 6 Adhesion mechanism of primers to ABS and PA

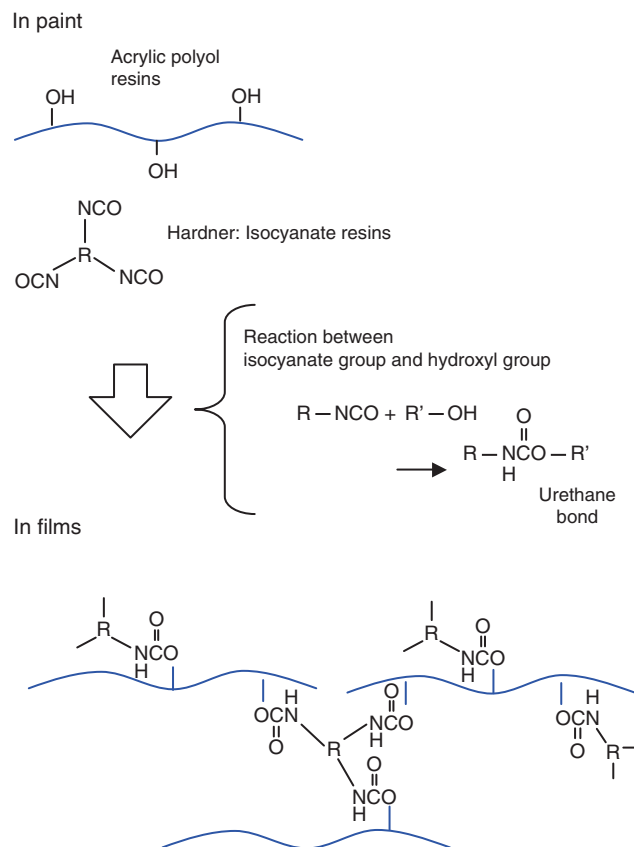


Fig. 7 Normal curing reactions

To avoid these defects, we added a preheating process between the processes of applying the primer and the top coat paint to release the water and increase the solid content ratio.

* **Solid Content:** The solid component containing no vaporizing substances such as water or solvent. In the case of painting materials, the solid content is the resin, body pigment, color pigment and additives. The solid content ratio is the ratio of the weight of the solid content to the overall weight, and is used both for a paint material before painting and for a wet film after painting.

3.3. Adjusting Viscosity to Stop Sagging While Maintaining Surface Smoothness

The solvent of the solventborne primer is made of organic material and has a high vaporization speed. Therefore, the solid content ratio goes up soon after the application and the viscosity increases as a result, contributing to the prevention of sagging during application. On the other hand, the solvent of the waterborne primer is water, which has a low vaporization speed. This leads to a low solid content ratio after the application, making it difficult to increase viscosity during application, and sagging occurs frequently as a result.

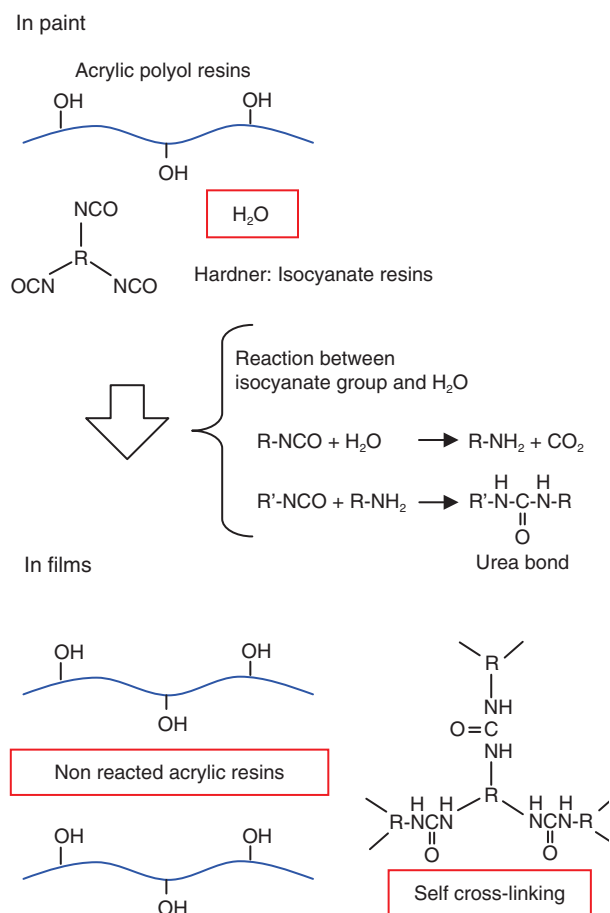


Fig. 8 Curing reactions with H_2O

The complexity in shapes of a motorcycle's plastic parts (Fig. 9) makes it difficult for an automated painting machine to follow the surfaces when applying the primer. This is why the primer tends to be applied unevenly or some portions even left unpainted with automated machines. Transfer efficiency and adhesion of the top coat film decrease if the primer film is uneven or missing. For those reasons, application of the primer requires painting work by hand. When the primer is applied by hand, the paint worker adjusts application conditions according to visual observations. The worker tends to apply paint repeatedly when he or she cannot get sufficient smoothness of the primer surface and that causes the film thickness to increase and results in sagging. Consequently, preventing sagging while maintaining the smoothness of the wet film is very important as requirements for manual painting.

One effective way to prevent sagging during application is to use a thixotropic rheology control agent to increase viscosity under low shear stress and decrease viscosity under high shear stress (Fig. 10). Therefore, in our development, we included an attempt to adjust viscosity by using a thixotropic rheology control agent in order to reduce sagging while maintaining surface smoothness.



Fig. 9 Example of motorcycle part with complex shape

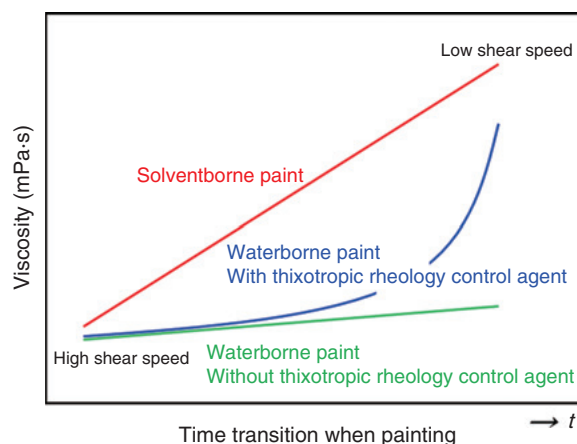


Fig. 10 Viscosity changes in painting process

4. Test Method

- (1) Test pieces:
 - (i) When tested with test panels:
Flat panels made of ABS, ABS+PE, PA with dimensions of $150 \times 70 \times 3.0$ mm
 - (ii) When tested with actual parts:
The front fender of the Honda VT750
- (2) Test procedures
 - (a) Adhesion Test:
The grid test method (JIS K5400) was applied. The top coat film was carved into 100 cells with a utility knife. Adhesive tape was applied to those cells and then removed. The conditions of removals in the top coat film were checked by visual observation.
 - (b) Water Resistance Test:
The test pieces were immersed in 40°C water for a set time period and then checked for defects such as blistering or removal of film.
 - (c) Humidity Resistance Test:
The test pieces were kept at an ambient temperature of 50°C with 95% humidity for a set time period and then checked for defects such as blistering or removal of film.
 - (d) Surface Smoothness Test:
 - (i) Primer film in wet condition: By visual observation.
 - (ii) Primer film in dry condition: By measuring R_a (roughness average) using a laser-type surface roughness measuring instrument. A cut off value: 0.8 mm.
 - (iii) Top coat paint in dry condition: By measuring LW (long wave) and SW (short wave) using BYK-Gardner Wave Scan. The instrument measures the amplitude of filtered wave forms of a surface through a certain wavelength range. The measured value represents good surface smoothness when the value is small. The value of LW is for the wavelength range of 1.2 to 12 mm, and SW is for 0.3 to 1.2 mm.
 - (e) Viscosity Test:
 - (i) Paint viscosity: Brookfield viscometer with rotation speed of 6 rpm.
 - (ii) Paint Viscosity of wet film: Cone plate viscometer with shear speed of 0.1sec^{-1} .
 - (f) Sagging Resistance Test:
Primer was applied to a vertical test panel with a hole of 5 mm in diameter. Preheating was applied while keeping the panel vertically positioned. The sag limit thickness is defined as the film thickness that generates 5 mm of sagging.
 - (g) Wettability Test:
After top coat paint was dropped onto a dry film of primer, the contact angle was measured using a protractor. Measurements of the contact angle were taken after 30, 60 and 90 seconds, and this data

was extrapolated to determine the contact angle immediately after the dropping of the top coat paint (0 seconds). A smaller contact angle means better wetness.

5. Results and Considerations

5.1. Designing Resin that Will Adhere to Both ABS and PA

In this development, emulsion type was selected as the mixture status of the waterborne primer resin, because of its high water resistance and high humidity resistance properties.

Four kinds of base resins were composed (shown in Table 3) with the combination of one selected principal chain, out of two kinds, and one selected functional group, out of three kinds, which were attached to side chains (shown in Table 2). Dispersion resins, additives and solvents were mixed with each base resin to make four kinds of primers, respectively, primer P-A, primer P-B, primer P-C, and primer P-D.

As the test pieces for paint substrates, three kinds of materials, ABS, ABS+PE and PA, were to be considered. Incidentally, ABS+PE is disadvantageous compared to ABS in respect of adhesion capability because ABS+PE contains PE by a few percentage points. Consequently, in these evaluation tests, only ABS+PE, which has greater difficulties in adhesion, was used to represent the tests for ABS and ABS+PE. In the next step, the primers prepared as above were painted onto the test pieces of ABS+PE and PA, the test pieces were preheated, and were painted with the top coat paint followed by bake-finishing. Adhesion tests were performed on those test pieces at the initial point of the entire tests followed by the adhesion tests after water resistance tests and humidity resistance tests.

The evaluation criteria for the adhesion test are: “good” if none of a hundred cells experienced exfoliations (denoted by circular symbol); “poor” if exfoliations occurred but less than 50% measured by area at any of the cells (denoted by triangular symbol); and “unacceptable” if any of the cells experienced exfoliations of more than 50% measured by area (denoted by cross symbol). The evaluation results are shown in Table 4.

The evaluation results of adhesion for Primer P-A and Primer P-B were good with ABS+PE, but unacceptable for PA. It was considered that these results came from the fact that carboxylic acid groups adhere well to ABS+PE but do not adhere well to PA. Primer P-C did not adhere well to ABS+PE but did adhere well to PA. It is predicted that adhesion occurred from dipolar interactions between the amide groups in Primer P-C and those in PA. Primer P-D did not adhere well to ABS+PE. The adhesion of Primer P-D with PA was evaluated as “good” but was considered as inappropriate for the final selection because swelling occurred after water resistance and humidity resistance tests. It was understood that the swelling occurred because of high water absorbency, in spite of good adhesion with PA, as sulfonic acids is more polar than carboxylic acids.

Table 3 Combination of principal chains and function groups in side chains

Base resin	Principal chain	Function group in side chain
A	Acrylic emulsion	Carboxylic acid group
B	Urethane emulsion	Carboxylic acid group
C	Acrylic emulsion	Amide group
D	Urethane emulsion	Sulfonic acid group

Table 4 Adhesion test results

Primer	Base resin	ABS+PE			PA		
		Initial	After WR	After HR	Initial	After WR	After HR
P-A	A	○	○	○	×	×	×
P-B	B	○	○	○	×	×	×
P-C	C	○	×	×	○	○	○
P-D	D	○	○	×	○	○ ⁽¹⁾	○ ⁽¹⁾

WR: Water resistance test, HR: Humidity resistance test

(1) Swelling, ○: Good, △: Poor (does not appear in this table), ×: Unacceptable

Table 5 Adhesion test results

Primer formula	Base resin			Compounding ratio (%)	ABS+PE			PA		
		Principal chain	Function group in side chain		Initial	After WR	After HR	Initial	After WR	After HR
P-AC1	A	Acrylic emulsion	Carboxylic acid group	50	○	○	○	×	△	○
	C	Acrylic emulsion	Amide group	50						
P-AC2	A	Same as above		25	○	○	○	○	○	△
	C			75						
P-BC1	B	Urethane emulsion	Carboxylic acid group	50	○	○	○	△	△	○
	C	Acrylic emulsion	Amide group	50						
P-BC2	B	Same as above		25	○	○	○	○	○	○
	C			75						

WR: Water resistance test, HR: Humidity resistance test, ○: Good, △: Poor, ×: Unacceptable

None of the four tested resins was qualified in both tests of adhesion to ABS+PE and to PA. Consequently, primer formulas P-AC1, P-AC2, P-BC1 and P-BC2 were made by mixing Base resin A or Base resin B, which have good adhesion characteristics to ABS+PE, with Base resin C, which have good adhesion characteristics to PA, while varying mixing ratios. Using these formulas, adhesion tests were conducted. Table 5 shows the mixing ratio of base resins and the results of adhesion tests.

All the Primer formulas in Table 5 satisfied the adhesion requirement to ABS+PE. However, the adhesion strength to PA varied from formula to formula. The adhesion strength was better in Formula P-AC2 when it was compared with Formula P-AC1, and was better in Formula P-BC2 when it was compared with Formula P-BC1. From these results, it was understood that the higher ratio of base resin C contributed to the higher adhesion strength to PA. In the comparisons of Formula P-AC1 with Formula P-BC1 and Formula P-AC2 with Formula P-BC2, the adhesion strength to PA was better in Formula P-BC1 and Formula P-BC2. It was considered that this was because the adhesion strength is improved when the urethane bonds in the urethane resin and the amide bonds in PA were attracted by the force of the hydrogen bonds.

These results showed that carboxylic acid groups contribute to adhesion to ABS+PE while amide groups and urethane resin contribute to adhesion to PA, and that a higher ratio of amide groups was needed to satisfy the adhesion requirements to PA. Through the evaluation processes mentioned above, Primer formula P-BC2 was eventually selected as the waterborne primer that was adhesive to both ABS+PE and PA.

5.2. Solid Content Ratio Control of Primer by Adding Preheating Process

The relationship between solid content ratio and paint performance was investigated, varying the temperature and the time of preheating processes, in order to get the solid content ratio of waterborne primer film that satisfies film requirements.

Test panels, mentioned in the Test Method section, were used for the test pieces. The setting time before the preheating was set at 3 minutes and preheating time was set at under 3 minutes, considering the paint hanger speed and the paint line length in the actual application to the manufacturing line. Four preheating (or drying) temperatures were set: room temperature, 40°C, 55°C and 70°C. Three

Table 6 Solid content ratio and film performance

Preheat condition	Primer		ABS						ABS+PE						PA						Judge-ment
	FT (μm)	SCR (%)	AP	AD	WR		HR		AP	AD	WR		HR		AP	AD	WR		HR		
					AP	AD	AP	AD			AP	AD	AP	AD			AP	AD			
RT×1 min	5	38.9	○	○	×	○	○	○	○	○	○	×	○	×	○	○	○	○	×	×	×
	9	33.5	○	○	×	○	×	×	○	○	○	×	×	×	○	○	○	○	×	×	×
	14	33	○	○	×	○	×	×	○	○	○	×	×	×	×	×	○	○	×	×	×
RT×2 min	5	43.5	○	○	○	○	○	○	○	○	○	○	○	×	○	○	○	○	○	○	×
	9	35.6	○	○	×	○	×	×	○	○	○	×	×	×	○	○	○	○	×	○	×
	14	35.1	○	○	×	○	×	×	○	○	○	×	×	×	○	○	○	○	×	○	×
RT×3 min	5	50.4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	9	38.1	○	○	○	○	×	○	○	○	○	×	×	×	○	○	○	○	×	○	×
	14	37.4	○	○	×	○	×	×	○	○	○	×	×	×	○	○	○	○	×	○	×
40°C×3 min	5	70.9	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	13	63.3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	18	56.2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
55°C×3 min	5	82.3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	10	74.7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	14	69.1	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
70°C×3 min	5	85.2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	12	80.3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	15	75.6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

RT: 23°C, FT: Film thickness, SCR: Solid content ratio, AP: Appearance, AD: Adhesion test (Initial),

WR: Water resistance test, HR: Humidity resistance test, ○: Satisfactory, ×: Unsatisfactory

coating thicknesses were set: minimum required coating thickness, maximum thickness without sagging and average thickness of those two. The primer was applied to the test panels of ABS, ABS+PE and PA, and the panels were then preheated, painted with the top coat paint and bake-finished. Appearance evaluation and adhesion test were conducted at initial condition, at the conditions after water resistance tests and at the condition after humidity tests.

Table 6 shows the results. The results show that, when dried at room temperature, only the panels dried for three minutes with minimum film thickness met the paint requirements. It was also proved that all the test panels were satisfactory to the paint requirements when they were preheated at any temperature higher than room temperature.

As for solid content, it was revealed that the solid content ratio required for satisfactory film performance was 50% or more. As for the condition settings, the values finally decided for the actual production were 70°C for the preheating temperature and 3 minutes for preheating time, considering size and shapes of the actual production parts and the quality assurance under mass-production lines.

5.3. Adjusting Viscosity to Avoid Sagging While Maintaining Surface Smoothness

The sag resistance and the surface smoothness were evaluated while varying the viscosity by adding rheology control agents without changing solid content ratio. The surface smoothness was evaluated through visual observations by on-site paint workers, using a front fender

Table 7 Sagging resistance and surface smoothness of painted wet film in changing primer viscosity

Primer viscosity (mPa.s)	Sag limit thickness (μm)	Surface smoothness of wet film
400	13	× (sagging across entire test panel)
700	21	◎
900	26	○
1800	27	△

◎: Better than current solventborne primer

○: Same as current solventborne primer

△: Worse than current solventborne primer

×: Out of permissible range

of the motorcycle as a painting subject, and comparing, immediately after painting, the wet film of the waterborne primer with that of the solventborne primer currently used. Table 7 shows the results of the evaluations. In the evaluation of the sag resistance, when the viscosity was under 700 mPa·s, the higher the primer viscosity was, the larger the maximum film thickness against sagging became. However, when the viscosity got over 900 mPa·s, the sag limit thickness hardly increased. The required primer viscosity should be over 700 mPa·s for the sag limit thickness of 20 μm , which is needed as the minimum requirement for paint work.

For surface smoothness, the lower the primer viscosity was, the higher the surface smoothness of wet film became. However, the sagging occurred across the entire test panel if

Table 8 Composition of waterborne conductive primer

Ingredients	Compounding ratio (wt%)	Function	
Water-soluble acrylic resin	1.3	Dispersion of pigments	Solid contents
Emulsion resin	13.2	Adhesion to substrate	
Pigments	10.4	Conductivity, Control of color	
Body pigments	0.8	Adhesion to glass filler	
Additives	1.6	Control of surface tension, Dispersion of pigments, Anti-bubble, Thixotrope	
Amine	0.2	Control of pH	Volatile contents
Water	70.3	Solvent	
Glycol	2.2	Coalescing agent	
Total	100		

the viscosity decreased to 400 mPa·s. The required viscosity ranged from 700 to 900 mPa·s to maintain equal or better surface smoothness of wet film compared to the current primers.

In conclusion, to satisfy the requirements of both sagging resistance and surface smoothness, the range of the primer viscosity should be between 700 and 900 mPa·s. 900 mPa·s was preferable in view of sagging resistance, while 700 mPa·s was preferable in view of surface smoothness. The primer viscosity was finally determined to be 900 mPa·s, because it should have been highly prioritized to maintain a larger tolerance for the paint workers' benefit.

Table 8 shows the final composition of the primer after resolving these three issues.

6. Achievements in Development

6.1. Reduction of VOC Emissions

The waterborne primer was developed to replace the current solventborne primers and was successfully applied to mass production. The waterborne primer contains 2.2% VOCs (Table 8) while solventborne primers contain around 70% VOCs. As a result, a 27% reduction of VOC emissions at the painting processes for plastic parts has been achieved. This contributed significantly to the 10 years of efforts in the Kumamoto factory for the total of 41% VOC reduction in the painting processes.

6.2. Unification of Primers for ABS and PA

The number of primers used in the painting processes were reduced from two to one and the work hours needed for the management and the administrative work for painting processes were significantly reduced. This also enabled the reduction of investment in facilities and equipment in the event of the installation of new painting lines.

Table 9 Surface smoothness of top coat paint

	LW(-)	SW(-)
On solventborne primer for ABS	14.3	40.5
On solventborne primer for PA	24.1	44.5
On waterborne primer	3.5	4.6

7. Secondary Benefits

This development was performed with the two objectives of the reduction of VOCs and the unification of primers for ABS and PA into one. However, other secondary benefits were obtained associated with those main objectives, such as the improvement in surface smoothness of the top coat film and the transfer efficiencies of the primer and the top coat paint. The details of those benefits are described below.

7.1. Enhancement in Surface Smoothness of Top Coat Film

To compare the surface smoothness of the top coat films on the currently used solventborne primer with that on the developed waterborne primer, surface smoothness (LW and SW) of the top coat films was evaluated. The results are shown in Table 9. From those results it was found that the surface smoothness of the top coat film on the waterborne primer was better than that on the solventborne primer was indicated in lower LW and SW values, ranging from 1/4 to 1/7 for LW and from 1/9 to 1/10 for SW, in spite of the viscosity adjustment (900 mPa·s) equalizing the surface smoothness of the wet films between the waterborne primer and the solventborne primer.

To investigate the reasons, the following points were evaluated.

- (1) Surface smoothness (Ra) of the dry films of the primers without top coat films.
- (2) Wettability (contact angle) of the top coat paint against the dry film of primers.
- (3) Viscosity of the primers in the wet films
- (4) Solid content ratio of the primers in wet films

The results are shown in Table 10. The waterborne primer showed smaller Ra with its dry film than the solventborne primer. This indicates that the surface smoothness of the dry films of the waterborne primer is greater than that of the solventborne primer. Moreover, the waterborne primer showed smaller contact angles with its dry film than the solvent-borne primer. This indicates that the wettability of the dry films of the waterborne primer is greater than that of the solventborne primer. From the above, we concluded that the surface smoothness of the top coat film had been improved by the superior surface smoothness and wettability of the dry film of the waterborne primer, when they were compared with the solventborne primers.

Table 10 Properties of primer films

	Dry film		Wet film	
	Ra (μm)	Contact angle ($^{\circ}$)	Viscosity (mPa·s)	SCR (%)
Solventborne primer for ABS	0.20	47.6	394,000	55
Solventborne primer for PA	0.39	43.0	over 1×10^8 (out of range)	60
Waterborne primer	0.15	41.2	16,560	30

SCR: Solid Content Ratio (=Non volatile content ratio)

The reason why the waterborne primer can provide superior surface smoothness and wettability of the dry film is considered as follows.

As for the reason for the superior smoothness, the viscosity of the waterborne primers in the wet films showed smaller values than the solvent-borne primer from Table 10. Therefore, it is estimated that the fluidity of the waterborne primers is higher than that of the solventborne primers (Fig. 11). Moreover, the solid content ratio of the waterborne primers in the wet films showed smaller values than that of the solvent-borne primers. This means that the larger volume change occurred in the transition from the wet-film state to the dry-film state while preheating the waterborne primers than in the transitions of solvent-borne primers, and it is assumed that that improved the surface smoothness (Fig. 11).

As for the reason for the superior wettability, it is estimated that it was due to the small Ra and the high

surface tension of the dry waterborne primer film, which has much higher polar functional groups compared with the solventborne primers.

7.2. Enhancement in Transfer Efficiency of Primer and Top Coat Paint

As another secondary benefit, a 9.5% efficiency enhancement of the primer transfer was observed in the waterborne primer compared to the solventborne primers. This can be explained by those reasons described below, which are presented as our assumptions.

Regarding the solventborne primers, which have high evaporation speed, the amount of flown-out and lost paint, without contacting the painting parts, is large because the paint particles lose their mass, and also there's a certain amount of paint that bounces back from the parts surfaces as the viscosity of the paint increases while the paint particles are travelling through the air. On the contrary, regarding

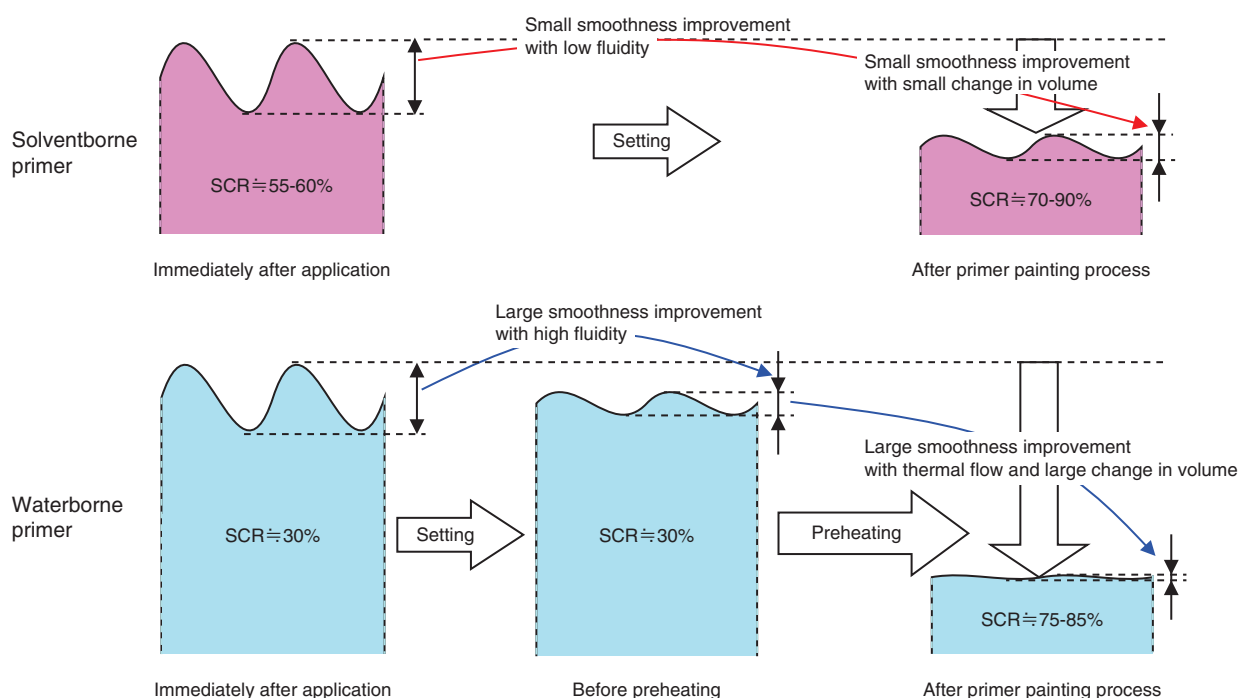


Fig. 11 Improvement of surface smoothness

the waterborne primers, which have low evaporation speed, the mass of the primer particles remains heavy, resulting in larger amounts of the primer reaching the painting parts, and the primer particles are easily captured at the surface of the painting parts and on the wet film formed in the process of painting as the viscosity of the paint remains low (Fig. 12).

The transfer efficiency of the top coat paint was enhanced as well on the waterborne primer compared to the solventborne primers. The reason can be understood that the top coat paint particles consecutively arriving at the primer coat surface are efficiently captured by the top coat paint already widely spread on the waterborne primer surface having good wettability, when compared with the solventborne primers.

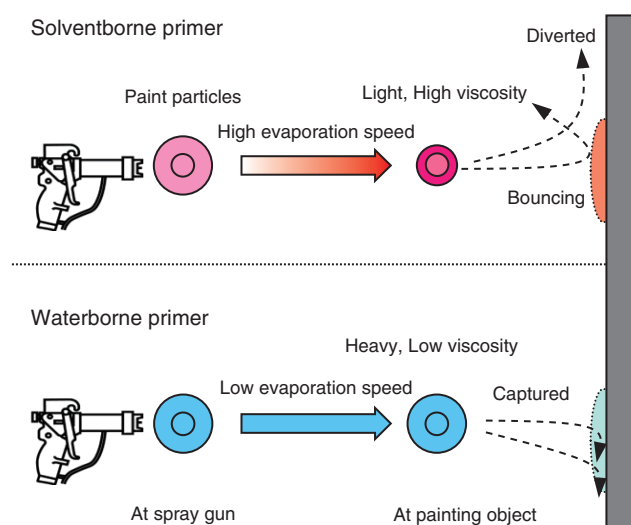


Fig. 12 Primer paint particles behavior

8. Summary

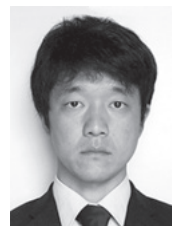
A primer that can be applied to both ABS and PA was successfully developed and the reduction of VOCs achieved by combining two different but dedicatedly designed waterborne resins. Through the application of this primer, a -40% reduction, which is the 2010 year reduction target of VOCs set by JAMA, was fulfilled. The application of this commonly usable primer enabled a reduction of the losses of time and materials in the painting lines. Moreover, thanks to the successful application of the waterborne primer, an enhancement of attractiveness in appearance was brought about by the enhanced surface smoothness, and the transfer efficiencies of the primer and the top coat paint were increased.

The primer developed here is already being applied in actual painting lines for plastic parts of motorcycle manufacturing in the Kumamoto Factory of Honda in Japan.

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