Application of Honda 3-Wet Primer-less Technology in Body Painting for Emission Reduction (CO_2 and VOC)

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ABSTRACT

Painting process has been part of automobile manufacturing since its beginning even though taking days to finish. Since it is related with car appearance and metal structure corrosion protection, the process has evolved to what was considered the industry mainstream: the 4-coat, 3-bake (4C3B). So coating is composed by layered structure applied in a particular order to achieve its functions. Even within years of evolution paint shops are still a large energy demanding area because of booths and baking ovens, resulting in elevated CO_2 and VOC emission. Due to its environmental footprint efforts have been made to develop new technologies both in material, changing from solvent to waterborne paints, and in painting process, attempting to shorten it. Therefore, 4C2B that eliminated primer oven and 3C2B primer-less paint systems were developed for many automobile manufactures but removing primer raises several issues as decreased stone chipping resistance and weather durability. In this context, 3C2B primer-less was successfully developed by Honda R&D Japan, by changing each layer function, keeping the same properties as the conventional process. It was successfully deployed in new Honda Itirapina automobile factory in Brazil due to key process controls resulting in great reduction of CO_2 and VOC emission.

INTRODUCTION

Since the beginning of the automotive industry about 100 years ago, body painting was part of cars manufacturing process, even though the first models did not employ an “automotive” specific paint which was applied by hand, required multiple coatings and sanding among them and took a long time to dry. This caused a serious production bottleneck resulting in about a week for the car to be ready for shipment and jamming warehouse floors of the automotive plant. Since then painting process greatly evolved both in terms of material and process, considering as critical performance driving factors: (a) aesthetic characteristics, (b) corrosion protection, (c) mass production, (d) cost and environmental requirements and (e) appearance and durability.

The automotive painting process has two essential functions: the first is related with appearance of the product (since it is inevitably the customers first contact with the vehicle) and the second is to protect the car’s metal structure from corrosion. To achieve these purposes the mainstream of automobile body painting is the 4C3B (4-coat, 3-bake) process which consists of electrodeposition, intermediate coating (primer), base and clear coating (the latter two also referred as topcoat), and each process is equipped with a painting booth and a bake hardening oven, illustrated in Figure 1.

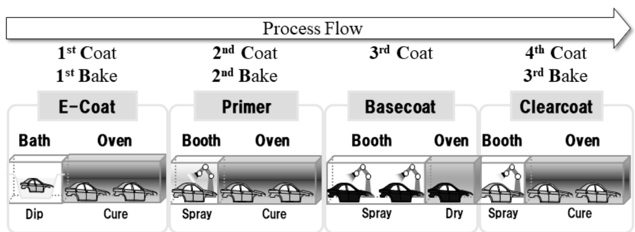

Figure 1. Representation of paint process and layer application steps to achieve final film structure.

The coating is applied in a particular order, resulting in a layered structure, and having different functionalities, represented in the Figure 2. Steps, layer composition and its respective function can be summarized as follows:

1. Pretreatment: removes and cleans excess metal and forms an appropriate surface structure enabling bonding of a corrosion protection layer.

2. Electrodeposition (ED) or E-Coat (1^{st} Coat): layer responsible for anti-corrosion or rust prevention.

3. Primer (2nd Coat): applied to promote adhesion between the E-Coat surface and the basecoat; it also imparts a smoother surface for subsequent layers, has anti-chipping and concealing properties (color purposes).

4. Base Coat (3rd Coat): contains the primary coloring pigment.

5. Clear Coat (4th Coat): provides a protective coating against environmental effects, corrosion, and UV light degradation, promotes unmatched color retention, and provides a glossy, smooth, and even finish.

Figure 2. Automotive coating layers, their thicknesses, and functions for an exterior surface [1].

Despite of years of evolution paint shops are still a major energy-demanding area of an automobile assembly plant, consuming 30%–50% of the total energy of the manufacturing [2], thus resulting in elevated CO_2 and VOC emission. This energy is used for air handling and conditioning (HVAC), as well as paint drying and treatment of emissions generated by paint droplets that are not deposited on automobile surfaces - the painting booths must be purged to remove evaporated solvent, overspray paint particles, and regulated pollutants (like Volatile Organic Compounds – VOCs). Hence, the energy associated with only booth ventilation is significant [3]. Although the energy used to dry a 100µm film on an automobile surface is not significant, it should be considered that paint drying includes heating of the paint combined with the metallic mass of the automobile body, dollies and carriers on which automobiles are moved through the painting process. [4]. It is estimated that over 60% of CO_2 emission from body manufacturing in automobile plants is generated in the painting process, as shown in Figure 3.

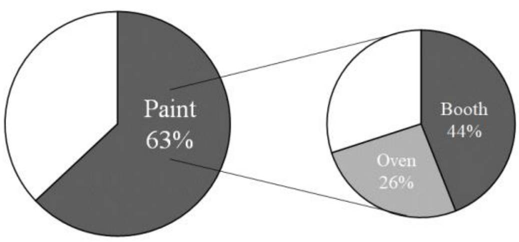

Figure 3. The amount of CO2 emissions from body factory [5].

To revert this scenario, in recent years efforts are being made in the manufacturing to shorten the process and reduce energy consumption, consequently reducing CO_2 and VOC generated. In the early 2000s, 4C2B (4-coat, 2-bake) painting, which eliminated the baking of the intermediate coating, relying only on drying step, was developed [6] and has been widely applied globally. In recent years, a 3-coat, 2-bake (3C2B) coating system, illustrated in Figure 4, which eliminates the intermediate coating itself, contributing to the emissions reduction, has been developed but it poses great technical challenges for the coating performance due to the specific function of the primer layer, as summarized in Table 1.

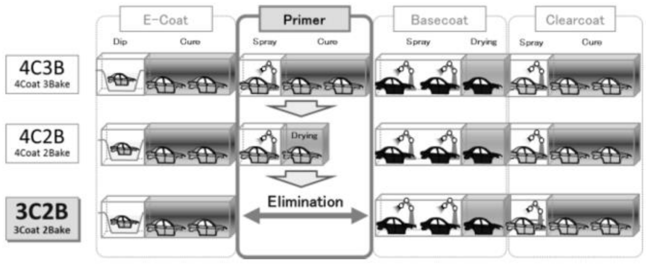

Figure 4. Paint application evolution to shorten the process and reduce emissions.

Table 1. Problems related with primer removal**.**

Problem	**Cause**
Chipping	Stress relaxation decreases by reduction of film thickness, and it easily leads to E-Coat peeling and consequently substrate rust.
Weatherability	Light, such as UV, will damage E-Coat, resulting in Top Coat peeling from E-Coat by photo degradation.
Appearance	The roughness of E-Coat surface is remained, and appearance (especially gloss) is negatively impacted.
Color Variation	Light colors (white, for example) have low hiding power and can impart in color variaton.

Another important movement to reduce environmental footprint of the coating process is focused on the paint material. Traditional automotive paint employs petroleum-based solvents as the volatile component, which discharge a large amount of VOCs. In the 1990s, a major development occurred in the formulation of automotive coatings: the use of waterborne basecoats, employing water as its main volatile component, thus greatly reducing VOCs emission [7], as shown in Figure 5.

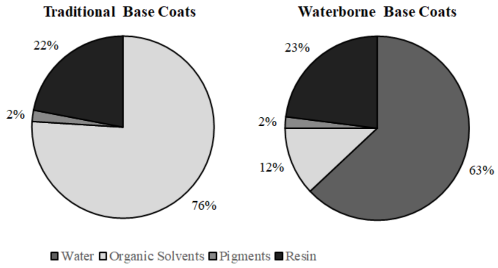

Figure 5. Traditional base coat (solvent borne) composition compared to waterborne base coat [7].

When the project of Honda new automobile factory plant (in Itirapina/SP) was approved, for the Paint Shop Concept Design, regarding the Environmental aspect, was proposed that it should lower its impacts compared to Sumaré/SP factory, reducing VOC and CO_2 emission withing the targets given. To achieve this goal, the new Honda 3C2B Primer-less waterborne based painting process was adopted [8]. Further details of its core technology to achieve a coating that is within the same level of 4C3B process in terms of performance and appearance but with lower emissions will be described in the next sections and also technical challenges for process controls in the manufacturing process in the factory.

MATERIAL DEVELOPMENT CONCEPT

Since the intermediate layer is omitted in the 3C2B coating system, the primer functions should be divided among the other layers which incorporate these functions so there is no detrimental effect on coating performance and appearance, as illustrated in the Figure 6.

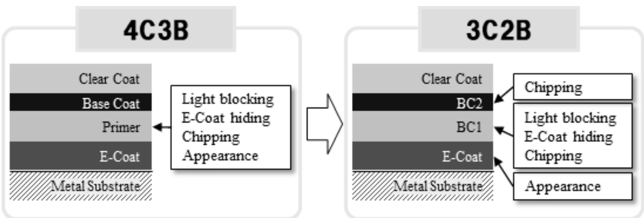

Figure 6. Division of primer function by layers.

E-Coat – until now the minute irregularities on its surface have been covered and concealed by the melt flow during the baking process using an intermediate coating. So, the surface roughness of the E-Coat will have a direct effect on the appearance of the overall paint film, especially the glossiness.

Base Coat 1 – chipping resistance and light rays blocking properties should be improved to ensure the same coating film durability as before.

About the first one, in the conventional painting process, the intermediate coat is baked and hardened after application, so there is a clear interface between the intermediate and base coats. Since there bake-hardening or drying process are absent in 3C2B, there is no clear interface, so the impact stress due to steppingstones is considered to concentrate between the E-Coat and BC1 layers. It was necessary to improve physical properties of the BC1 coating film, such as coating film absorption energy and interfacial adhesion with E-Coat, compared to conventional intermediate coating materials, situation illustrated in Figure 7.

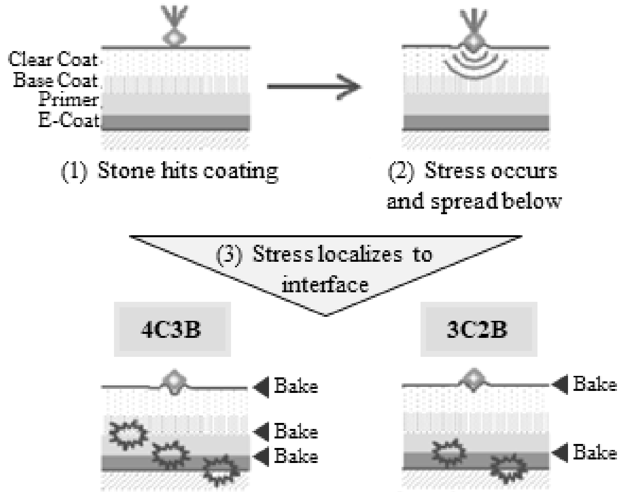

Figure 7. Image of propagation of stress by chipping damage [9].

Also, in terms of weather resistance, the intermediate coating used to block harmful rays such as ultraviolet rays, but with its elimination, the medium to high brightness colors could not fully absorb the light, reaching the E-Coat. As a result, it photo-degrades the bis-phenol resin, the main binder, and the top coating film peels off over time. Increasing the pigment concentration above a certain level improves light rays blocking properties and helps with E-Coat levelling, even with a thinner film than the conventional intermediate coating. Figure 8 summarizes the concept of securing weather resistance in this painting process.

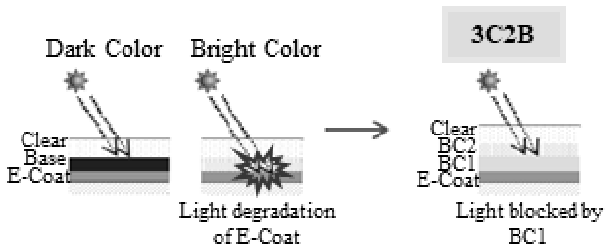

Figure 8. Representation of damage by light rays [9].

Base Coat 2 – keeps color function but some chipping resistance is added as well.

Clear Coat – keeps same previous function (appearance and weather resistance).

Properties improvements of each layer are summarized in Table 2.

Table 2. Summary of layers properties improvement.

Performance Item	Required Function	Layer			
		E-Coat	**BC1**	**BC2**	**Clear Coat**
Chipping Resistance	Stress relaxation		●	●	
Weather Durability	Light shielding		●		
Color Variation	Hiding of E-Coat		●		
Appearance	Surface smoothness	●	●		

Subtitle: ● Property improvement

ENHANCE BC1/BC2 CHEMICAL INTERFACIAL MIXING CONTROL – as mentioned before, in 3C2B short process system, BC1 and BC2 are applied wet-on-wet, with no heat drying between them, which tends to cause mixed layers (interfacial mixture). So, the key to this coating process is how to control the reaction of each coating film during the coating process for the design concept described in the previous section to function properly, otherwise the performance and appearance of the coating could be compromised, and impair negatively in color, since the orientation disorder of the luster pigment causes color unevenness, as can be observed in Figure 9, with microscopic images of coating cross section.

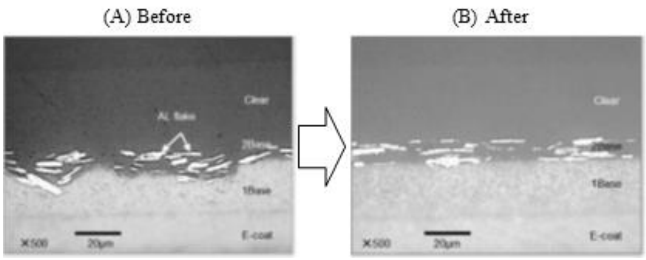

Figure 9. Paint cross section of separated interface with (A) and without (B) orientation disruption through BC1 viscosity control [9].

To avoid mixing layers the BC1 viscosity should be rapidly increased after it was applied (a value higher than 250 Pa.s is desirable) [9] and the percentage of non-volatile within the specified range (values depend on paint supplier).

However, at the BC1/BC2 interface, some level of resin mixing is considered to exist although is not microscopically visible. This fact was evidenced evaluating the interface between BC1/BC2 using Fourier-transform infrared spectroscopy (FTIR) [9]. It consists of low molecular weight resin (Mw 2500 or less) which migrates within the interface, as shown in Figure 10. This explains why sufficient chipping resistance could not be ensured unless a chipping function is added to BC2.

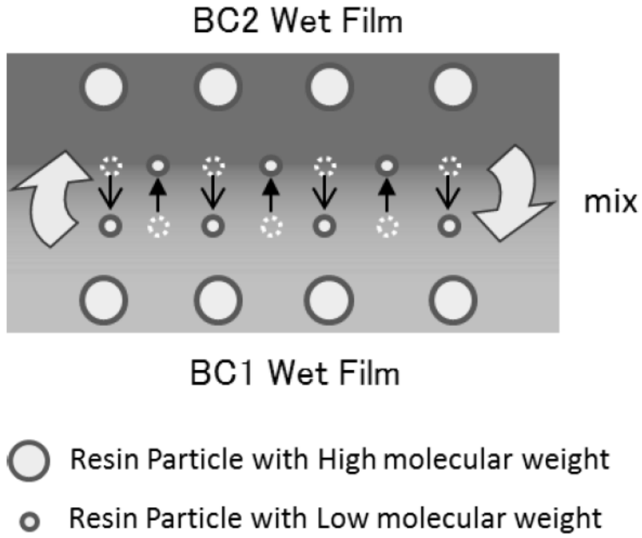

Figure 10. BC1/BC2 interface during application where some mixing occurs in the layers interface [9].

APPLICATION OF 3C2B PRIMER-LESS IN NEW FACTORY

For the material concept performs as expected, new automobile factory in Itirapina should strictly control some key points of the painting manufacturing process, which are listed and described below:

- E-Coat Roughness: since this property will directly impact the appearance of the coating (gloss), a roughness value should be controlled.

- E-Coat Dirt: in the conventional 4C3B process, since all layers are baked, Quality Gates in between process are a common practice, so before the Topcoat application, two inspection, sanding and body cleaning gates are possible (E-Coat and Primer inspection), aiming to achieve the lowest rate of Topcoat rework. Since the primer is removed in the 3C2B process, Quality Gates are also reduced. To keep the same low-rate of Topcoat rework, E-Coat inspection should be intensified, and Pretreatment / E-Coat process baths filtration strengthened, to achieve lower levels of E-Coat sanding.

- Application Booth Cleanliness: for the same reason as above, Topcoat being applied wet-on-wet and reduction of Quality Gates availability, booth cleanliness should be guaranteed to avoid contamination of the coating (for example, dirt and crater) and consequently increase in rework rate.

- Paint Viscosity: as mentioned in the previous section, for the coating to perform as expected, layers mixing should be minimal. So, viscosity control within the specified range is important to result in clear interfaces between BC1 and BC2 layers.

- Paint Non-volatile Percentage: BC1 and BC2 non-volatile content during the application should be measured and controlled in production, for the same reason as paint viscosity, and also for hiding power purposes and sagging control. Measurements after 2 minutes of application and right before the next layer application are important control values.

- Booth Temperature and Humidity: should be strictly controlled inside the optimal range of operation to guarantee viscosity and paint non-volatile to be according to the material concept, as shown in Figure 11.

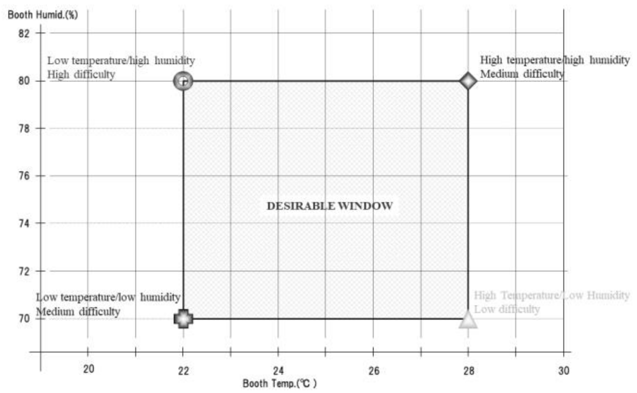

Figure 11. Optimal range of booth temperature and humidity for proper paint applicability and performance.

These key points were essential for the successful application of 3C2B waterborne primer-less process in the new Itirapina factory.

REDUCTION OF CO_2 AND VOC EMISSION – considering a production of 120.000 cars/year, the new 3C2B waterborne primer-less process adopted in Itirapina can reduce around 10% of CO2 (Figure 12) and 60% of VOC (Figure 13) emissions compared to the traditional 4C3B solvent borne process previously employed in Sumaré [10], thus contributing to lower environmental footprint of painting process.

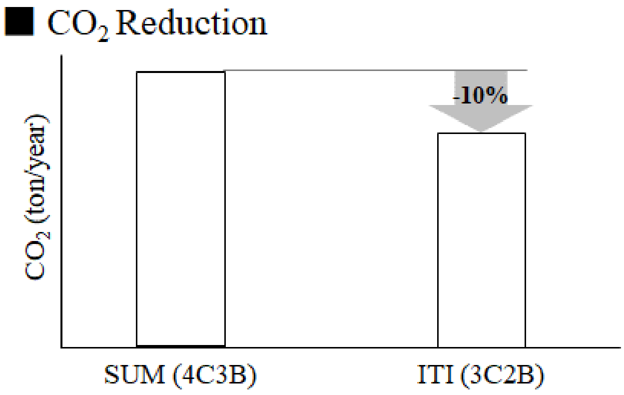

Figure 12. Reduction of 10% ton/year of CO2 compared with the traditional process**.**

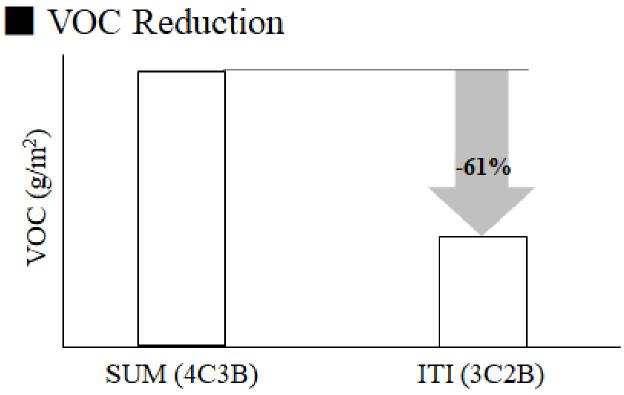

Figure 13. Reduction of 61% g/m^2 VOC compared with the traditional process.

CONCLUSIONS

Development of the 3C2B short process imposed great challenges with the removal of primer and its important functions. But it was possible to redesign the layer concept and redistribute its functions among the others. In result, performance, appearance, and weather durability of the coating remained like the traditional 4C3B coating.

During its implementation in the Itirapina new factory, key items in the process should be strictly controlled, since the layers are applied wet-on-wet, as E-Coat roughness, BC1 and BC2 viscosity and its non-volatile application content, and booth temperature and humidity control. These items guaranteed the coating to perform as expected.

The successful application of this short process led to great reductions in CO_2 (-10%) and VOC (-60%) thus contributing to reduce environmental footprint of automotive painting process.

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