

Development of a Predictive Model and Identification of Influencing Factors for the Millimeter-Wave Transmittance of Coatings

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The automotive industry is undergoing rapid technological innovation driven by CASE and carbon neutrality initiatives, increasing the importance of advanced safety technologies related to autonomous driving. Millimeter-wave radars are widely installed in vehicles to enhance safety; However, increasing the concentration of conductive metallic flake pigments, such as aluminum flakes, improves the aesthetic appearance of automotive coatings but reduces millimeter-wave transmission performance when radar sensors are mounted behind a bumper. Therefore, achieving both an attractive appearance and high millimeter-wave transmissivity has become an important requirement in automotive coating design.

In this study, we extended a previously developed fundamental model for predicting millimeter-wave transmission performance and investigated the effects of various metallic effect pigment parameters on transmissivity. The following findings were obtained:

- (1) Using a coating internal structure analysis technique, the internal structure and arrangement of flake pigments in actual coating were characterized and transformed into a periodic structural model(Fig.1). The developed model enables the prediction of millimeter-wave transmissivity with practical accuracy and computational efficiency(Fig.2).
- (2) Based on the developed model, the thickness direction distance, particle diameter, and overlap count of the flake pigment were revealed to be the most influential parameters affecting the transmission coefficient S21, with the thickness direction distance being the dominant factor.
- (3) From an energy perspective, the structural arrangement and geometric parameters of the flake pigments strongly influence reflection at the coating surface, while having little effect on absorption within the coating (Table 1, Table 2).
- (4) The results suggest that appearance can be controlled by the in-plane direction distance of flake pigments, whereas millimeter-wave transmissivity can be controlled by the thickness direction distance, particle diameter, and the overlap count of flake pigment. Therefore, it may be possible to achieve both attractive appearance and high millimeter-wave transmission performance simultaneously.

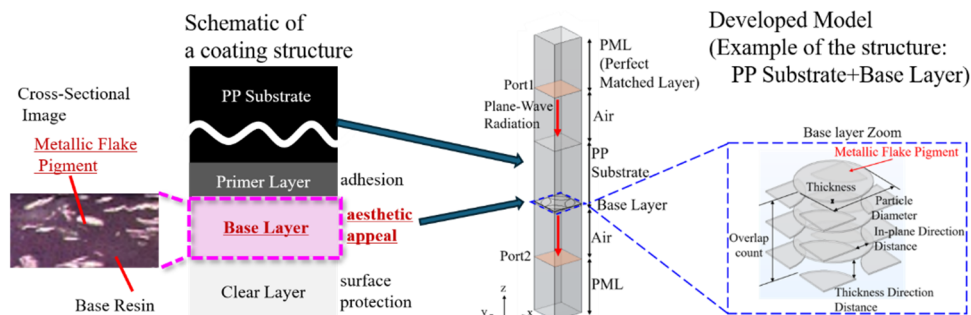


Fig. 1 Millimeter-Wave Transmittance Prediction Model for Coatings Developed in This Study

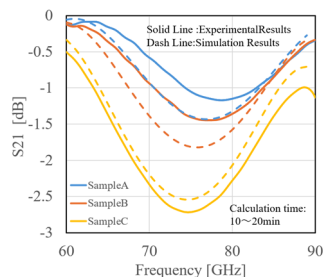


Fig. 2 Validation of the Developed Model (PP Substrate + Base Layer)

Table 1 Comparison of Energy Balance for Different Thickness Direction Distance

Thickness Direction Distance[μm]	0.1	1.0	2.5
Transmitted Energy[%]	31.0	65.3	67.8
Reflected Energy[%]	65.3	28.0	24.3
Absorbed Energy[%]	3.7	6.7	7.8

(In-Plane Direction Distance:1.0μm , Thickness:0.2μm, Overlap Count:6, Particle Diameter:10μm)

Table 2 Comparison of Energy Balance for Different Particle Diameter

Particle Diameter[μm]	5	10	20
Transmitted Energy[%]	71.1	65.3	44.8
Reflected Energy[%]	20.8	28.0	50.1
Absorbed Energy[%]	8.0	6.7	5.1

(Thickness/In-Plane Direction Distance:1.0μm , Thickness:0.2μm, Overlap Count:6)