Analysis of Material Properties and Structural Factors on Impact Resistance of Door Trim

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A Digital Twin technology becomes widely used, improving the prediction accuracy of impact performance is an important issue. In particular, against the background of stricter safety standards for side impacts, the importance of evaluation and prediction techniques for the impact resistance of interior resin parts is increasing.

On the other hand, although resin parts have high design flexibility, evaluation and prediction are made difficult because material properties being unclear, such as stiffness non-uniformity caused by complex geometries, resin-specific nonlinear behavior, ductility, and anisotropy.

While crack occurrence in door trims may be attributable to material composition and other material-related causes or to structural causes, it is not clear which is the primary factor. The combined effects of these material- and structure-induced factors make assessment and prediction of impact performance highly challenging.This study aims to establish a method that can separate and evaluate the two factors, in order to clarify whether attention should be focused on material-related or structure-related causes for crack prevention.Impact characteristics are considered describable by quantitative mechanical physical quantities such as Young's modulus, fracture load, absorbed energy, strain, and viscoelasticity. Under the hypothesis that correlations between material factors and structural factors can be understood through these physical quantities, correlation analysis was conducted by combining methods such as material testing, component-level tests (bench tests), and CAE analysis.In this study, we verify the correlation between the impact performance of actual parts and the material properties, and report the main factors obtained.

It is necessary to quantitatively evaluate the impact properties as accurately as possible. The Charpy test focuses on localized fracture behavior. In contrast, the puncture impact test applies pressure over a wider region and can therefore account for fracture behavior occurring inside the material. In this study, the puncture impact test was selected because it exhibits smaller scatter and provides a larger amount of information than the Charpy test.The puncture impact test was conducted under the test conditions specified in ISO 6603-2:2000 (JIS K 7211 2:2006). The tests were performed using a HYDRO SHOT HITS P10 high-speed impact testing machine (Shimadzu Corporation).In this study, a bench test was also conducted to simply simulate a side-impact vehicle test. In this setup, the door trim panel was fixed to a metal fixture, and the impactor was driven into the side-impact PAD region and the armrest region.In this study, a bench test was also conducted to simply simulate a side-impact vehicle test. In the correlation diagram shown in Figure1, it was found that materials with low impact resistance can be classified in the lower left region, whereas those with high impact resistance can be classified in the upper right region.On the basis of the preceding results, We found a correlation between the material properties and the structural factors. This correlation occurs in resin components under loading conditions similar to the puncture impact test.

For the armrest region, a correlation was obtained among the puncture energy, the strain transmitted to the component, and the crack initiation location and timing observed in the bench test. In this study, we further examined the relationship between impact resistance and internal structure using a series of analytical techniques. A distinct correlation was identified between the rubber content quantified by NMR analysis and the puncture energy. However, for microstructural features related to impact resistance-such as lamellar bundle morphology-the current measurement techniques were insufficient to fully clarify the underlying mechanisms. Elucidation of these mechanisms remains a subject for future investigation. To establish a quantitative correspondence between the panel impact test and the bench test, measurement datasets obtained through a physical parameter commonly accessible to both testing configurations were integrated. This procedure enabled a rigorous association between intrinsic material properties and macroscopic structural attributes. The analysis further demonstrated a statistically significant correlation between impact resistance and the rubber content constituting the internal polymer structure. In contrast, the contribution of finer microstructural features-particularly lamellar bundle morphology-to the impact-resistance mechanism could not be conclusively ascertained within the limitations of the present characterization methods. Clarification of these mechanistic aspects will require future investigations employing higher-resolution structural analyses and advanced multiscale evaluation techniques. Although clarifying unknown factors such as the interfacial condition remains a challenge, efforts to address these issues will continue. In addition, we aim to apply the evaluation and analysis methodology established in this study toward practical implementation as a material-selection approach based on defined performance requirements.

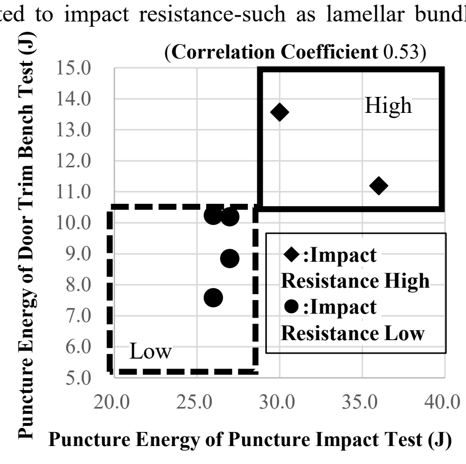

Fig.1 Correlation of Puncture Energy between Puncture Impact Tests and Bench Test