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STUDY FOR DYNAMIC BEHAVIOR OF SHOCK ABSORBING MATERIAL : EFFECT OF NUMERICAL MATERIAL MODELS

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ABSTRACT

For the design of transport packaging based on the analysis, it is one of the most important factors how to consider dynamic behavior of shock absorbing materials. In this study, wood is selected as the most popular shock absorbing material, and the appropriate numerical material model of wood is proposed from viewpoint of deformation.

For numerical material models of wood, all the specific characteristics should be considered, such as anisotropy due to grain direction, which has significantly greater compressibility than metal materials, and strain rate dependence. In the lastest study of our dynamic analysis[1] for transport package using LS-DYNA code, The "Modified Honeycomb" numerical material model defined in the code was adopted and solid element's formulation prepared for this material model was combined. This material model can define independent stress-strain curves in three axes direction in the cartesian coordinate system. For the evaluation of the 9m vertical, horizontal, and slap-down drop tests with the 1/3 scale model, the analysis using LS-DYNA code resulted in the good agreement concerning deceleration of the package body and the crushed height of shock absorber along the drop direction. However, regarding the deformation of wood not along the drop direction (lateral direction of it), relatively large disagreement was shown in the analysis results. This disagreement may be caused by independency of stress-strain curves in three axes. There is possibility that this disagreement causes the difference of drop behaviours in some drop conditions such as secondary impact of slap-down drop.

Therefore, in this study, some numerical material models and appropriate element formulations are picked up and these combinations are compared by applying to the various kinds of actual crush test of wood specimens. Three numerical material models, "Crushable foam", "Wood", and "Modified Honeycomb" with appropriate element formulations are selected for this study. After that, the analyses for each 9m drop test are conducted, and combination of appropriate numerical material model with solid element formulations to have good agreement for the deformation is discussed.

1.INTRODUCTION

In recent year, CAE software like dynamic analysis code LS-DYNA[1)] has come to be widely used for product development, research, and evaluation. In particular, as increase of computer resource is significant, this makes it possible to improve the accuracy of analysis using CAE software. As for LS-DYNA, it has become possible that atomization of the mesh, application of element formulation types with many integration points, adoption of complex numerical material models including nonlinear behaviour, and so on. Moreover the LS-DYNA was developed in the 1970s and nowadays is used beyond impact analysis with more features and numerical material models being added every year. Therefore, it is important to select appropriate numerical material model from wide variety of them.

In this study, for transport/storage packaging that wood is used as the shock absorbing material, it is discussed about appropriate combination of numerical material model and solid element formulation type.

2.STUDY BASED ON THE CRUSH TEST OF WOOD SPECIMEN

As the shock absorbing material for transport/storage packaging, wood is commonly selected. Wood has grain as shown in Fig.1, and resistance force against compression along to grain direction (which is called as 'parallel to grain') is significantly stronger than the other directions (which are called as 'perpendicular to grain'). On the other hand, not same as metal materials, expansion in a direction other than the compression axis is not observed, and each axis tends to behave independently.

In this section, in order to confirm the behaviour along to the compression axis, analysis for the crush test of wood specimen has been performed.

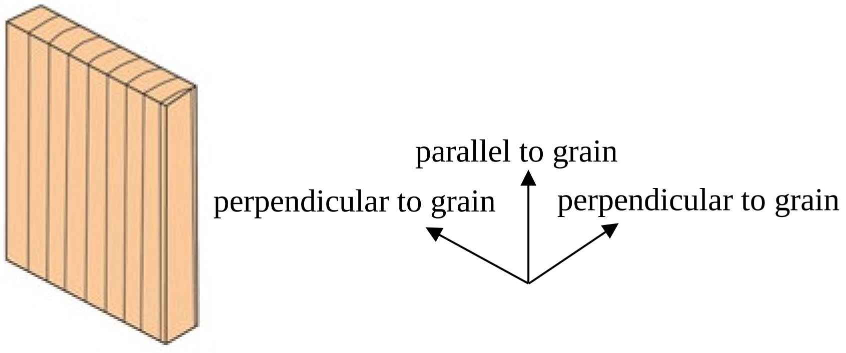


Figure 1 Wood image for calculation of stress-strain curve

2.1. Crush test of wood specimen

As the shock absorbing material for transport/storage packaging, dynamic shock absorbing property of redwood which is a kind of woods has been obtained with the crush test of wood specimen[2)]. The size of specimen made with redwood was φ40 mm x 43 mm, and the weight was dropped onto the specimen from 9m height as shown in Fig. 2.

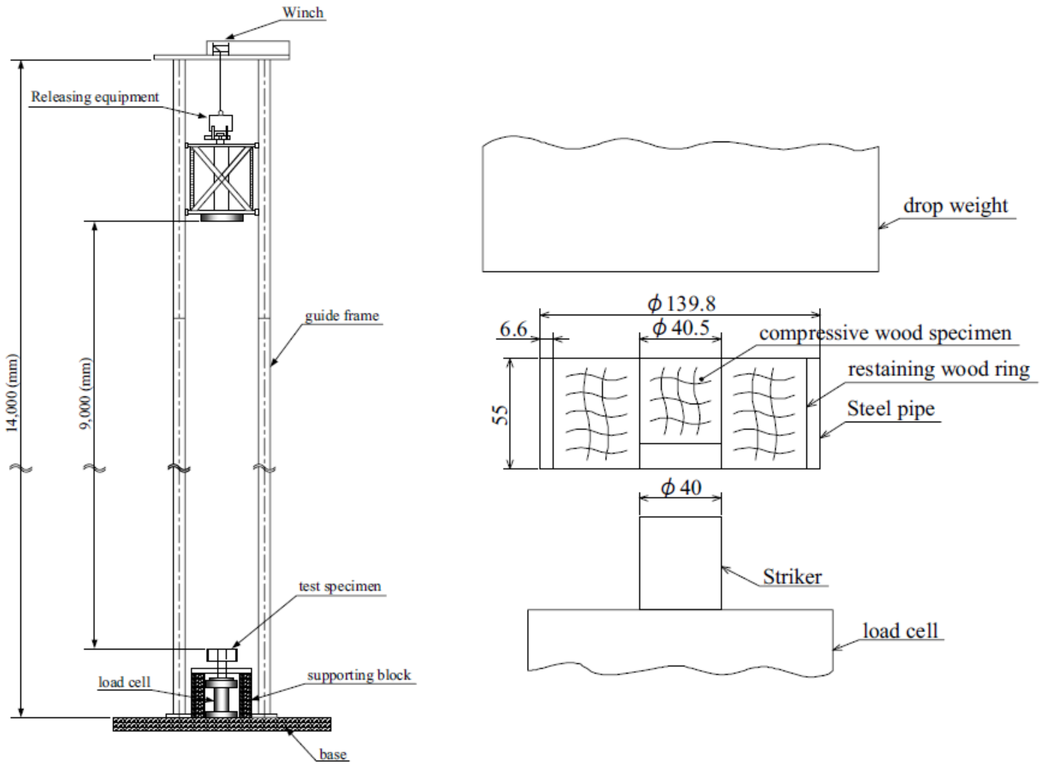
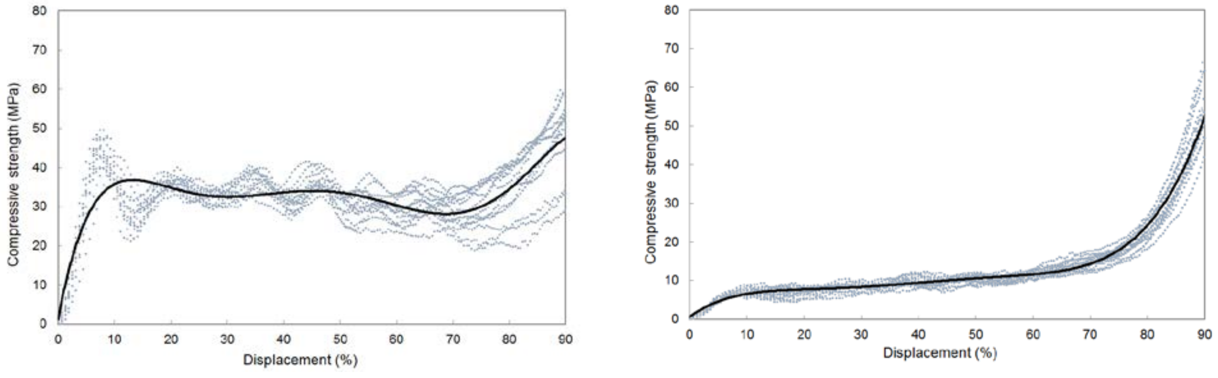


Figure 2. Equipment of dynamic compressive test$^{2)}$

2.2. Stress-strain curve of wood

The redwood's stress-strain data actually obtained by the dynamic crush test at room temperature are shown as dots in Fig. 3. As the input data for LS-DYNA, one approximate curve is defined from these actual data, which is shown as solid lines in the Fig. 3.

To represent the dynamic shock absorbing property of wood, these stress-strain characteristics should be considered.



(1) Parallel to grain (2) Perpendicular to grain

Figure 3 Stress - Strain curve generated by the measurements

2.3 Analysis condition for the crush test

To confirm reproducibility of dynamic shock absorbing property of wood in LS-DYNA, the analysis of element compression test was conducted. The analysis model was a cubic three-dimensional solid element of 100 mm on a side. The compressive load up to 90% deformation was applied on the upper surface of the solid element of which lower surface was fixed.

And the following numerical material models are applied to this analysis.

- *MAT_MODIFIED_HONEYCOMB (*MAT_126)
  This numerical material model can represent multi-curve approximation of stress-strain curve along to crush axis, and anisotropy for other axis can be controlled.
- *MAT_CRUSHABLE_FORM (*MAT_063)
  This model is also able to represent multi-curve approximation of stress-strain curve. However it is consisted for crushable form, so it has isotropic characteristic.
- *MAT_WOOD (*MAT_143)
  As the name suggests, it is consisted for the very wood, and anisotropy can be considered. However, stress-strain curve in the numerical material model can represent only as bilinear curve.

Also concerning the element formulation types for the solid element, it is chosen appropriately from the following.

- Constant stress solid element (EQ.1)
  This element formulation type is the default of LS-DYNA. Integration point is just 1, and calculation cost is very low. However, under large deformation condition, accuracy of the analysis can be uncertain.
- Fully integrated S/R solid (EQ.2)
  As the general high integrated element formulation type, it is selected.
- Fully integrated S/R solid intended for elements with poor aspect ratio, efficient formulation (EQ.-1)
  It is almost same as the EQ.2, but modification for distorted element is applied.
- 1 point corotational for MAT MODIFIED HONEYCOMB (EQ.0)
  This element formulation type is consisted only for the *MAT_126.

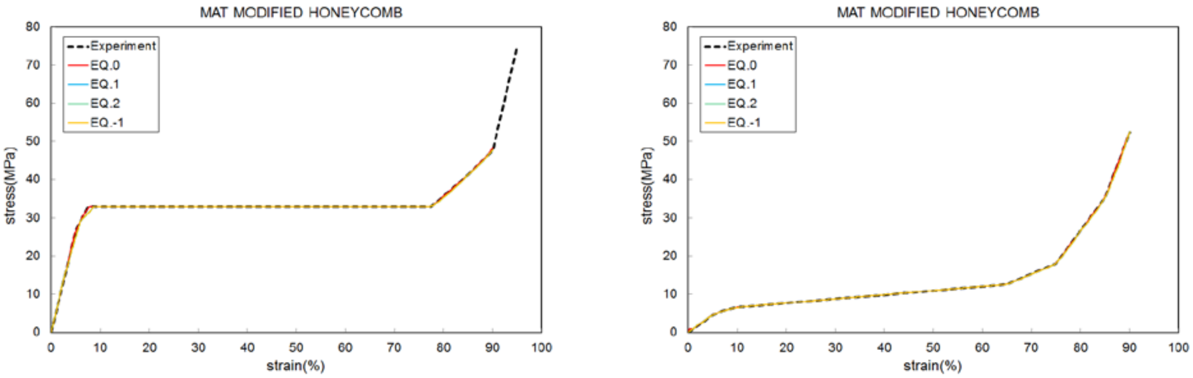
Combinations of the numerical material models and the element formulation types in this study are shown in Table 1.

Table 1 Combinations of the numerical material models and the element formulation types

	*MAT_126	*MAT_063	*MAT_143
EQ.1	Case 1-1	Case 2-1	Case 3-1
EQ.2	Case 1-2	Case 2-2	Case 3-2
EQ.-1	Case 1-3	Case 2-3	Case 3-3
EQ.0	Case 1-4	---	---

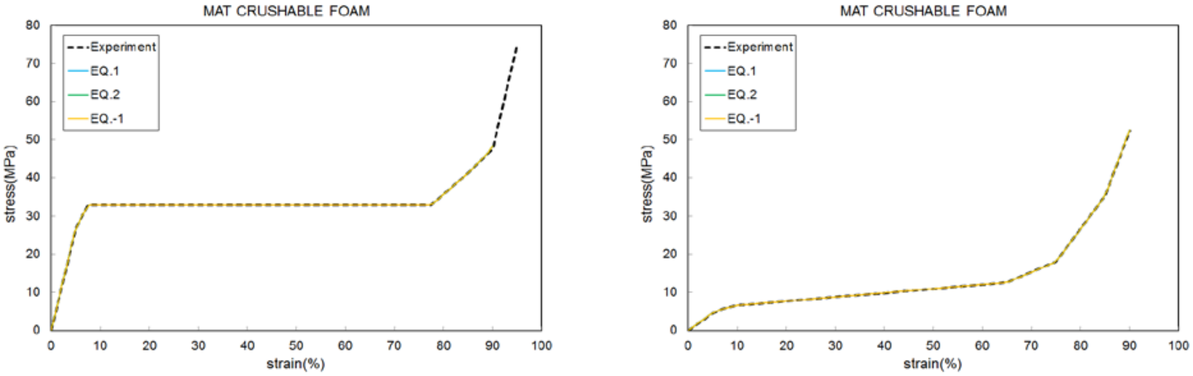
2.4 Analysis Result of the crush test

Results of the analysis for the crush test are shown in Fig. 4 through Fig. 6.
As shown in Fig. 4 and Fig. 5, for *MAT_126 and *MAT_063 these analytical results closely reproduce its experimental data for the crush test regardless combination with either the element formulation types.
On the other hand, as shown in Fig. 6, analytical results of *MAT_143 cannot represent the experimental data correctly. Because stress-strain curve in this numerical material model is represented as bilinear curve.
Therefore, *MAT_126 and *MAT_063 are appropriate to be applied for the wood material whose stress-strain curve is represented with multi-curve approximation. In addition, it has been confirmed that the elemental formulation types do not affect the analytical result in analysis of simple deformation behavior such as the analysis of the crush test.



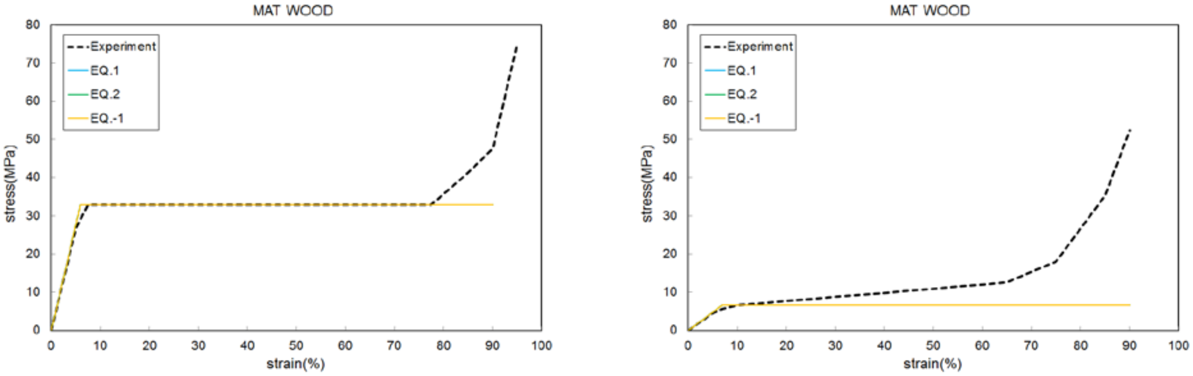
(1) Parallel to grain (2) Perpendicular to grain

Figure 4 Comparison of stress-strain curve for *MAT_126



(1) Parallel to grain (2) Perpendicular to grain

Figure 5 Comparison of stress-strain curve for *MAT_063



(1) Parallel to grain (2) Perpendicular to grain

Figure 6 Comparison of stress-strain curve for *MAT_143

3. STUDY BASED ON THE DROP TEST OF TRANSPORT PACKAGE

We, Transnuclear and Kobe Steel, had been performed 9m drop test with 1/3 scale model of a transport/storage package [3) 4)]. The 1/3 scale model, which is shown in Fig.7, is designed based on actual transport/storage package, and dummy content is installed to simulate weight and center of gravity. Drop height is 9m from the target floor and drop test conditions are horizontal, vertical and slap-down with inclined angle of 5 degree.

In addition, analysis of the drop test with LS-DYNA has been also performed [5)]. In these study, the 1/3 scale model for the drop test is accurately modeled as shown in Fig.8. As numerical material model for wood, which is shock absorbing material on the analysis model, *MAT_126 has been used.

In this section, concerning *MAT_126 and *MAT_063 which are discussed in section 2, impact for analysis result when applying various element formulation types is discussed with the drop test result of 1/3 scale model and its analysis model.

Figure 7 Outer view of 1/3 scale model[4)]

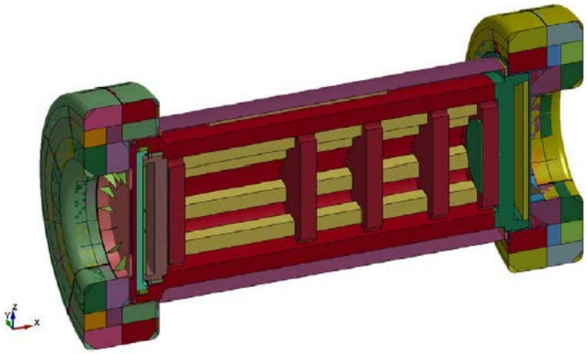


Figure 8 Analysis model[5)]

3.1 Analysis Condition

In order to confirm influence on the analysis result of the drop test by applying the combination of the numerical material models of wood and the element formulation types discussed in Section 2, the combinations of * MAT_126 and * MAT_063 shown in Table 1 are applied as wood model to the drop analysis model used in the previous research. For this confirmation, the following drop conditions are selected from the actual drop test.

- Vertical drop: In this condition, deformation of wood in the shock absorbing cover is almost axial compression only. Therefore wood's characteristics relative to the compression axis would greatly affect the result.
- Slap-down drop: In this condition, deformation of wood in the shock absorbing cover is very complicated. Therefore, wood's characteristics against multi axial deformation such as restraint to other than the compression axis, would greatly affect the result.

3.2 Analysis Result of the drop test

For each analysis case, ratio its analysis result against the actual drop test result has been calculated concerning the maximum deformation of the top and bottom shock absorbing cover (SAC) and the maximum deceleration generated in the top part and bottom part of the packaging. The results and also its standard deviation among the cases are shown in Table 2. Regarding to * MAT_126 and * MAT_063, there is no significant difference of analysis results between all cases, except for the maximum deceleration in the top part of the packaging under slap-down drop condition.

However, in the Table 2, only maximum values are compared. Especially concerning deceleration, it has time history such as shown in Fig.9 and it is desirable that not only the maximum values but also the time histories of acceleration during drop phenomenon similar to the others.

Therefore, focusing on the deceleration in the top part of the packaging during secondary impact because the highest deceleration would be occurred, similarity of the time histories has been compared. For this comparison, as shown in Equation (1), difference of decelerations at the same time between one analytical result and actual drop test result (shown as ⊿d in the Fig. 9) is integrated along time histories during secondary impact (shown as 'secondary impact' in the Fig. 9).

$$\mathrm{DW} = \sum \Delta t \cdot \sqrt{(\Delta d)^2} \qquad \ldots\ldots (1)$$

here, DW: Differences of wave form

Δt: Time interval

Δd: Difference of decelerations at the same time between one analytical result and actual drop test result

The values of DW calculated for each analysis case are shown in Fig.10 as a comparison. Regarding the *MAT_126 (case 1-1 through case 1-4), the case 1-1 is less similarity (DW is large). This shows that element formulation type with one integration point other than EQ.0 (case 1-4) is not suitable for *MAT_126. On the other hand, case1-2 and case1-3, to which are applied element formulation types with high integration points, shows higher similarity (DW is small) than case 1-4 which had been applied in previous studies. In addition, regarding the *MAT_063 (case 2-1 through case 2-3), similarities of all cases are slightly less than case 1-4. Therefore, it should be taken care when you use the *MAT_063.

Table 2 Ratio its analysis result against the actual drop test result

Condition	Items	Case							standard deviation
		1-1	1-2	1-3	1-4	2-1	2-2	2-3	
Vertical drop	Deformation - Top SAC	1.42	1.39	1.39	1.32	1.46	1.42	1.46	0.05
	Deceleration - Top - Bottom	1.06 0.94	1.07 0.96	1.04 0.94	1.09 1.06	0.94 0.84	1.02 0.94	0.85 0.87	0.08 0.06
Slap-down drop	Deformation - Top SAC - Bottom SAC	1.23 1.15	1.21 1.04	1.23 1.04	1.12 1.03	1.15 1.06	1.09 1.04	1.11 1.04	0.06 0.04
	Deceleration - Top - Bottom	1.42 1.34	1.39 1.14	1.34 1.15	1.26 1.20	0.98 1.18	1.06 1.19	1.11 1.18	0.16 0.06

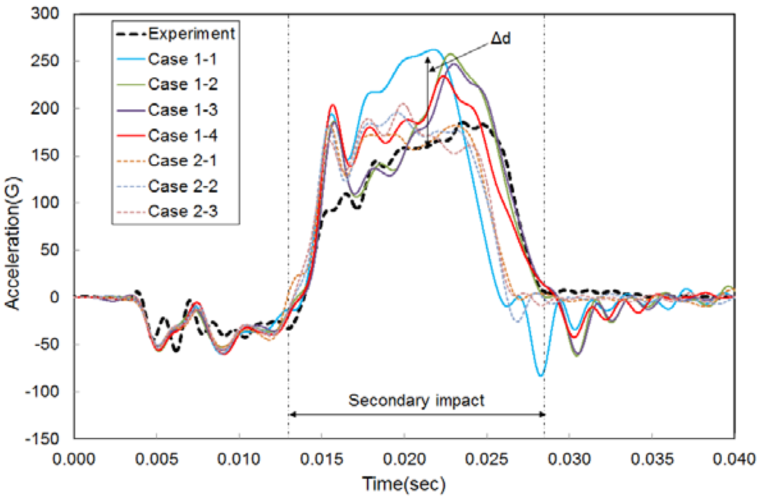


Figure 9 Time history of deceleration of slap-down drop in the top part of the packaging

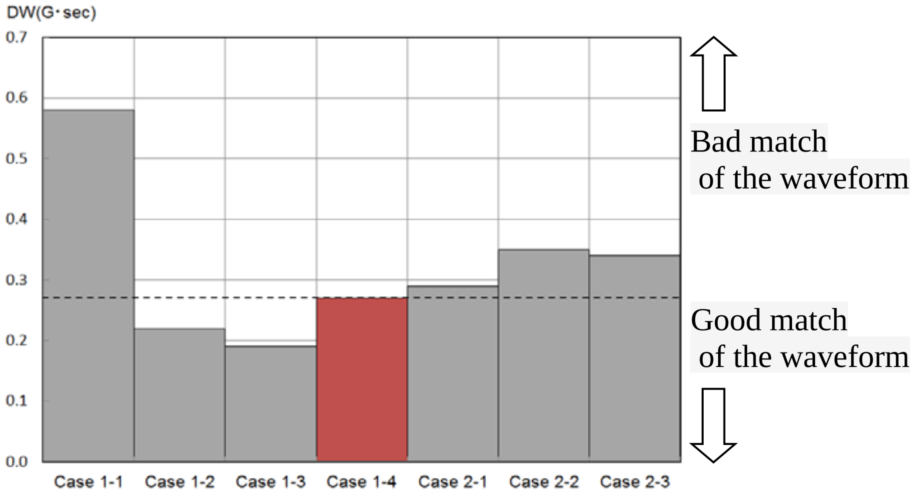


Figure 10 Calculation result of DW

4. CONCLUSION

In this study, it has been discussed about the combination of appropriate numerical material model and the element formulation type to have good agreement with the drop test result, with regard to redwood used as shock absorbing materials for transport/storage packaging, and concluded as follows.

- From the reproduction analysis result of the crush test of wood, *MAT_126 and *MAT_063 has been selected as appropriate numerical material models for wood.
- From the reproduction analysis results of actual packaging's drop test with 1/3 scale model, *MAT_126 or *MAT_63 shows good agreement in maximum values of the drop test result, but it should be taken care for using *MAT_063.

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