Simulation of Compression Behavior of Paper Product Using *MAT_PAPER

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Abstract

*Environmental pollution caused by plastic products is now a global serious problem. Plastics dumped in the ocean become into micro plastics and threaten the living environment of various organisms. In order to reduce such environmental pollution, products are being developed using paper materials with less environmental impact as an alternative to plastic products. In developing a paper product, it is necessary to design a strength suitable for the application. Therefore, accurate prediction of product strength by simulation is considered to be very important for product development. In this study, we attempt to predict the strength of paper products using *MAT_PAPER, which is a paper material model implemented in LS-DYNA®. Since *MAT_PAPER is a complex anisotropic elasto-plastic composite constitutive equation, properties of paper materials were measured, and the reliable input parameters were determined. A paper cup compression test and simulation were performed using the paper material model which was constructed from the test. As a result, a good agreement and some differences between the experimental results and the simulation results is shown*

Introduction

An excellent constitutive model which can be used to simulate very complex nonlinear behavior of paper has been implemented from LS-DYNA R8.0 released in 2015 as *MAT_PAPER or *MAT_274[1][2]. In this research, *MAT_PAPER was applied to a compression test of very common paper cup and the simulation using this material model was compared with a real compression test and the result was demonstrated. *MAT_PAPER is orthotropic elastoplastic model and the following measurement tests are required to identify exact material properties (Coordinate convention for paper material is shown in Fig.1).

(1) In-plane tensile test for MD direction
(2) In-plane compression test for MD direction
(3) In-plane tensile test for CD direction
(4) In-plane compression test for CD direction
(5) In-plane shear test
(6) Out-of-plane tensile test for ZD direction

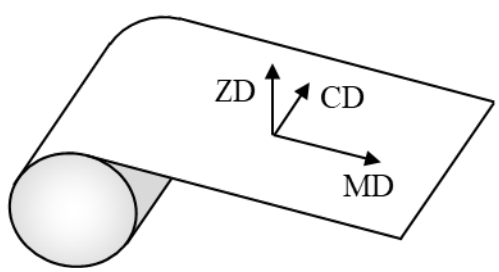


Fig. 1 Conventional coordinates of paper material

(7) Out-of-plane compression test for ZD direction
(8) Out-of-plane shear test

In this research, (1), (2), (3) and (4) of above tests were executed and other material properties were given from the references.

Measurement test of paper cup material

The paper cup and the test specimens are shown in Fig.2. Specimens were cut out from the body of the cup along vertical direction as the MD direction and circumferential direction as the CD direction. Average width and thickness of specimens are 29.544 mm and 0.287 mm respectively. A typical tensile testing machine was used for the test. The specimens were clamped and tensioned or compressed with the speed of 0.6 mm/min. The test configuration is shown in Fig.3. The tensile and compression tests were repeated several times and averaged stress-strain curves were obtained. The stress-strain curves from the tests are shown in Fig.4.

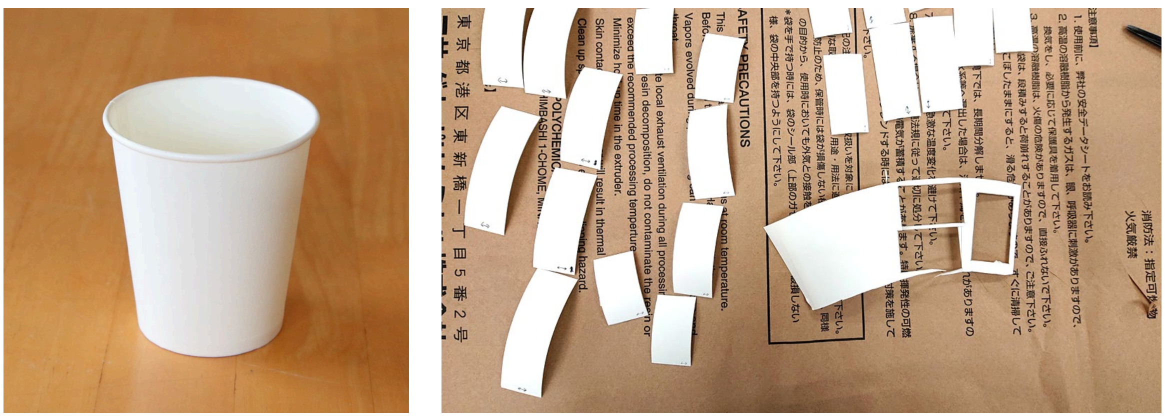


Fig.2 Paper cup and specimens

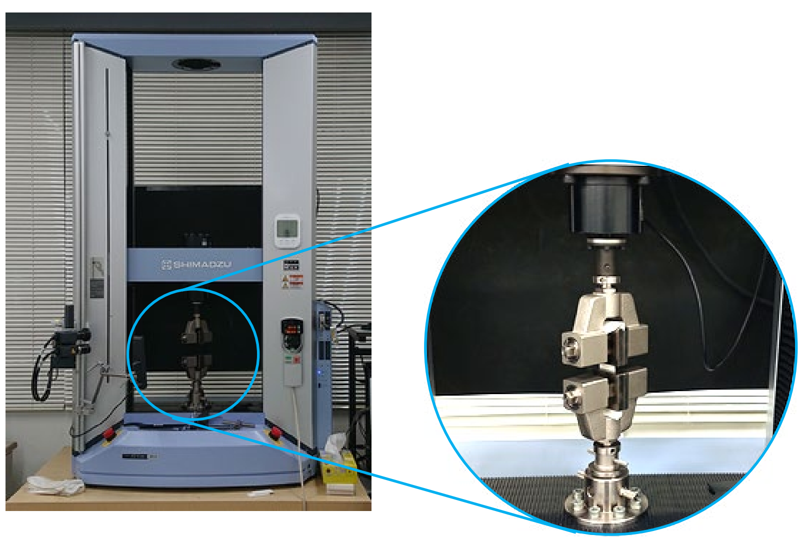
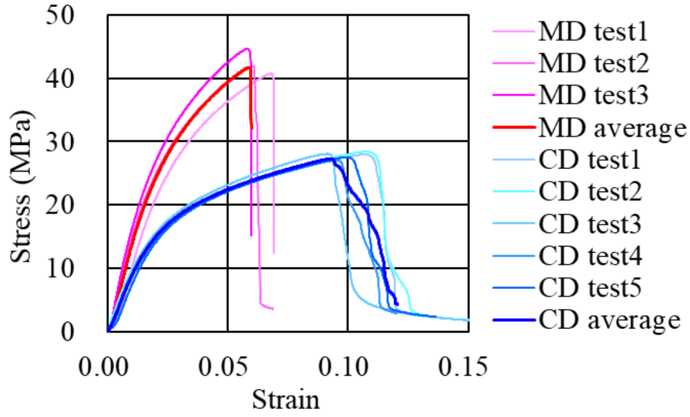
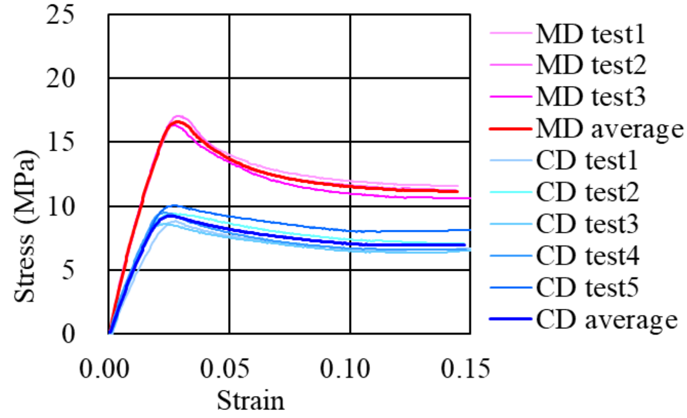


Fig.3 Test configuration



(a) Tensile test



(b) Compression test

Fig.4 Stress-strain curves measured in the test

Analysis model of paper cup

A simple paper cup model was generated for the validation as shown in Fig.5. The body of the cup is separated into three parts with different thickness. The cup is modeled using shell element type 16. The upper rim is modeled using beam element type 1 and offset outside of the cup. Detailed dimensions are also shown in Fig.5. The material properties and stress-strain curves used in the simulation are shown in Table 1 and Fig.6. The slope of stress-strain curves after failure is modified and the yield stresses are increased as 10 MPa. These modifications are done to avoid numerical instability during the simulation. The shear stress-strain curve in Fig.6 is generated as the average of tensile and compression curves in CD direction. Elastic constants and elastic Poisson's ratios are taken from the reference as it is difficult to measure these values by simple tensile test.

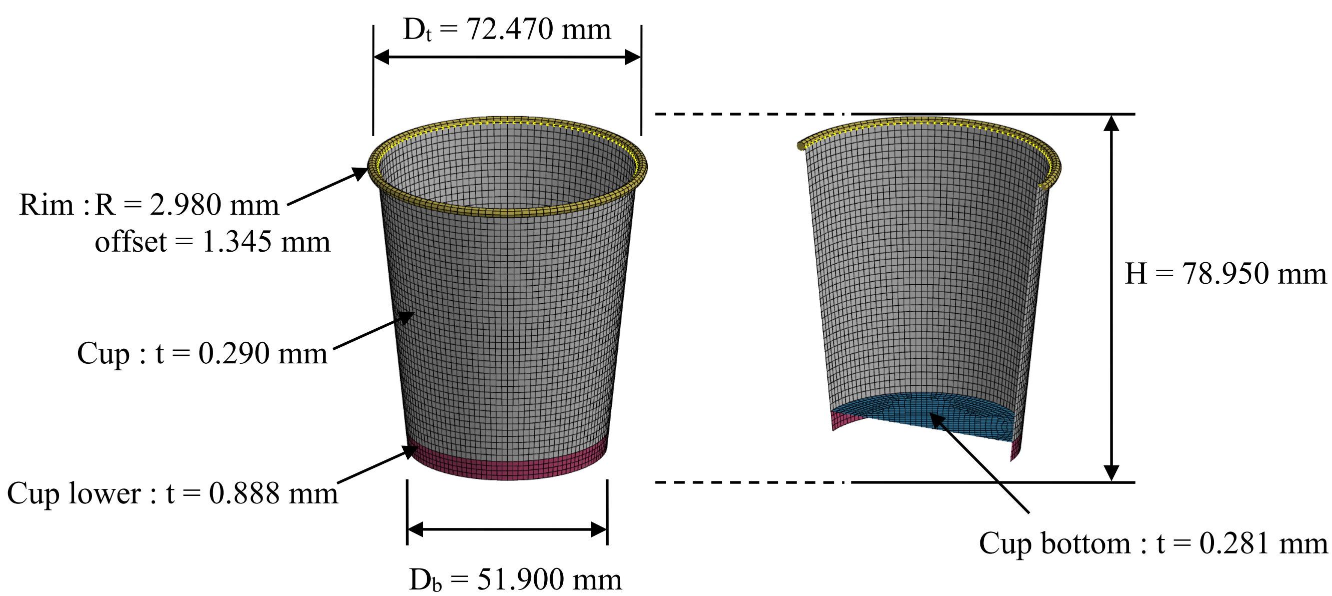


Fig. 5 Cup model geometry and dimensions

Table 1 Material properties of *MAT_PAPER

Variables	Value	Reference
RO (ton/mm3)	5.941E-10	Weight of cup = 3.82 g
E1 (MPa)	3400.0	[3]
E2 (MPa)	960.0	[3]
E3 (MPa)	960.0	[3]
PR21	0.10447	modified from [4]
PR32	0.10447	modified from [4]
PR31	0.10447	modified from [4]
G12 (MPa)	800.0	[3]
G23 (MPa)	800.0	[3]
G31 (MPa)	800.0	[3]
E3C (MPa)	-	not used for shell element
CC	-	not used for shell element
TWOK	4.0	[3]
S01, S02, S03, S04, S05	-LCID	Stress-strain curve ID
PRP1	0.5	LS-DYNA default
PRP2	0.133	LS-DYNA default
PRP4	0.5	LS-DYNA default
PRP5	0.133	LS-DYNA default
ASIG (MPa)	0.4378	[3]
BSIG (MPa)	-1	[3]
CSIG	6.5	[3]
TAU0 (MPa)	2.5	modified from [5]
ATAU (MPa)	2.0	modified from [5]
BTAU	2.0	[5]

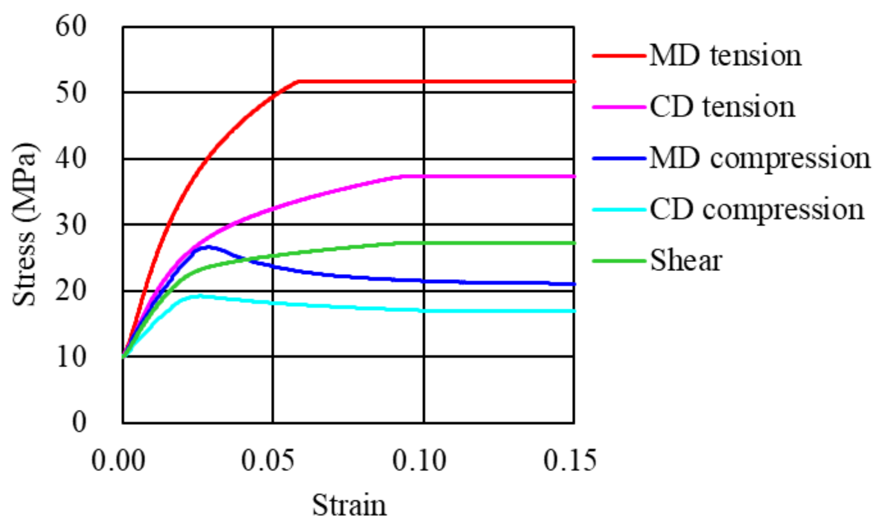
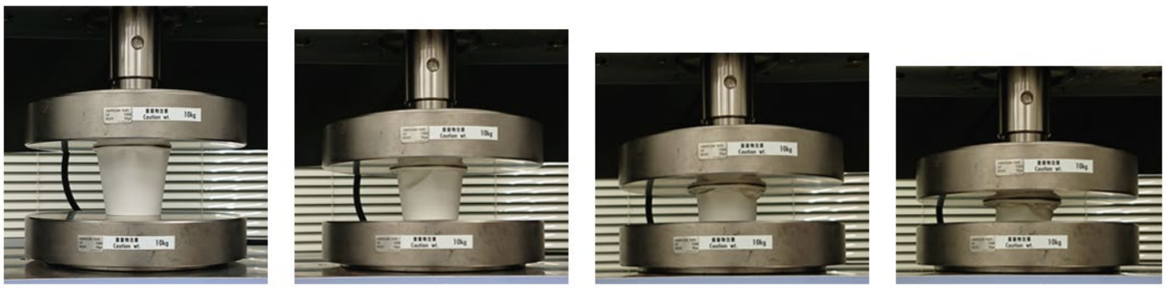


Fig. 6 Stress-strain curves used in *MAT_PAPER material model

Simulation of compression test of paper cup

Compression test of paper cup was performed to evaluate the accuracy of the material model. Figure 7 shows the deformation of the cup for the real test and the simulation. The tests were performed four times and averaged force-stroke curve was obtained.



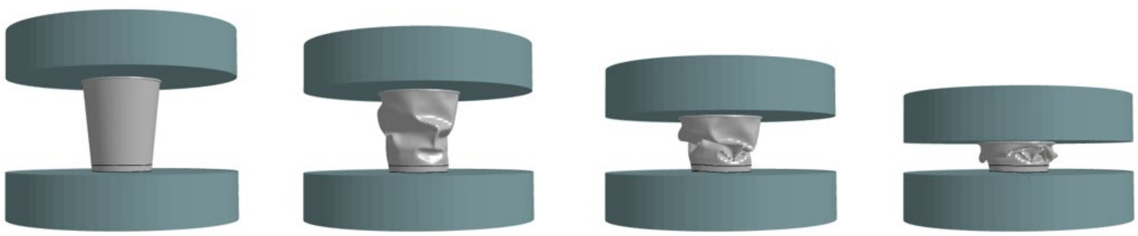


Fig. 7 Comparison of deformed shape of paper cup between test and simulation

Results and discussion

The force-stroke curves from the test and the simulation are shown in Fig. 8 and some differences can be seen in this figure. The first peak of the curve from the simulation is very high. The levels of plateau of both test and simulation are similar. Further, the force of the simulation is very higher than that of the test beyond the stroke

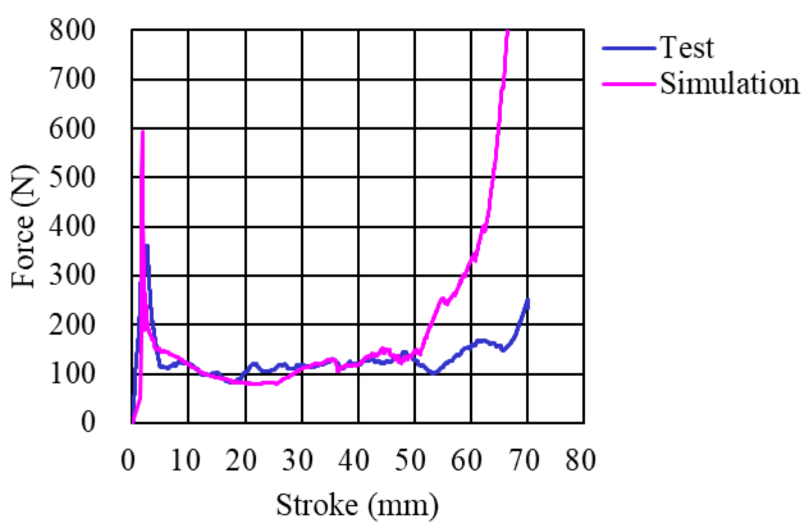


Fig. 8 Comparison of force-stroke curve of test and simulation

of 50 mm. It is supposed that the height of the first peak may be dominated especially by elastic behavior of the material. Hence, it is considered that more precise measurement for yield stress and Young's modulus is needed. Since it is considered that the force in the range beyond the stroke of 50 mm is mostly determined by the stress-strain curve in the range of large strain, further investigation is required to treat rapid decrease of stress-strain curve without numerical instability. Another possibility to achieve good correlation is the consideration of any in-plane failure mechanism.

Conclusions

An application of *MAT_PAPER on the modeling of ordinary paper material product was reported in this research. This material model showed relatively good agreement with the test result. However, Numerical instability (error termination with NaN nodal velocity) happened when the yield stress was very small or stress-strain curve contained rapid decrease. So further investigation for the modeling technique of paper material to perform stable computation is necessary as a future work.

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