Evaluation of influence of temperature below 80 ℃ and strain rate on compressive property of wood for shock absorber

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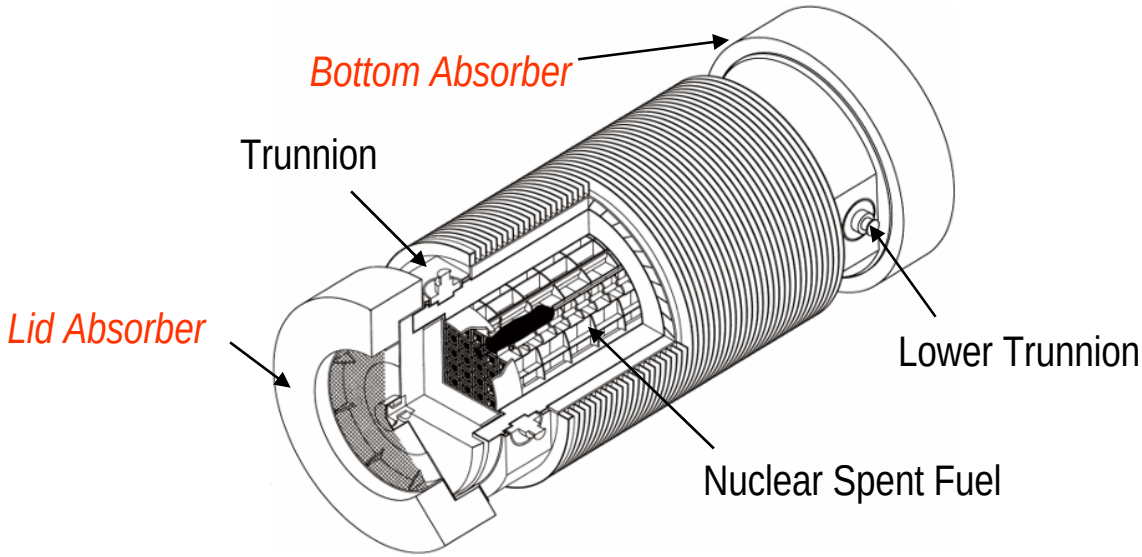
Background

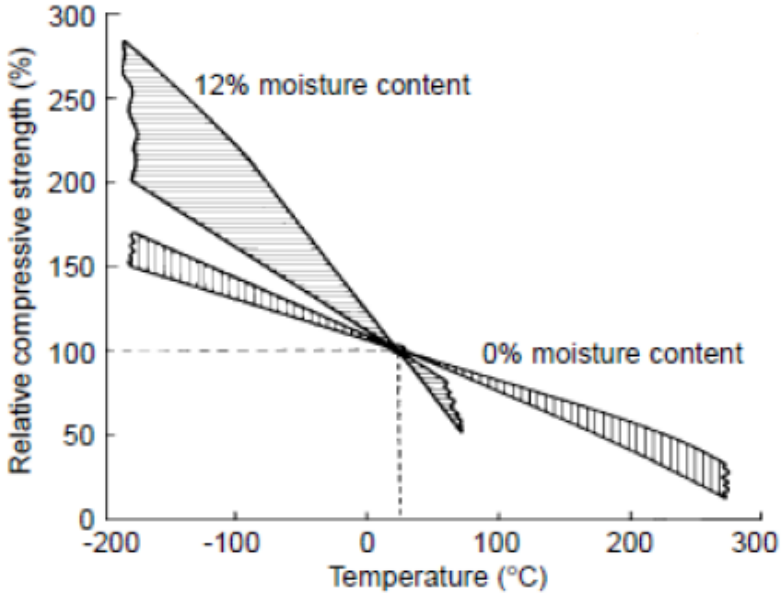
- *Transport cask for nuclear spent fuel is required to maintain the structural integrity subjected to the impact loading, such as 9m drop test*
- *Shock absorbers attached to the both ends of cask should*
  - *Absorb all the kinetic energy without bottoming*
  - *Prevent high accelerations to protect the containments*
- *For shock absorbent materials, wood materials, which have relatively with high specific strength, large crushing capacity and easy processing, are often usually used.*
- *To design effective shock absorbers, appropriate material characteristics should be applied.*



Example of Nuclear Spent Fuel Transport Cask

Objective

- *Wood for shock absorbent material has naturally temperature dependency.*
- *There is a possibility that the impact acceleration increases as the wood becomes soft with the increase of temperature and as a consequence reaches to a locking-up point due to the remarkable deformation of shock absorbers*

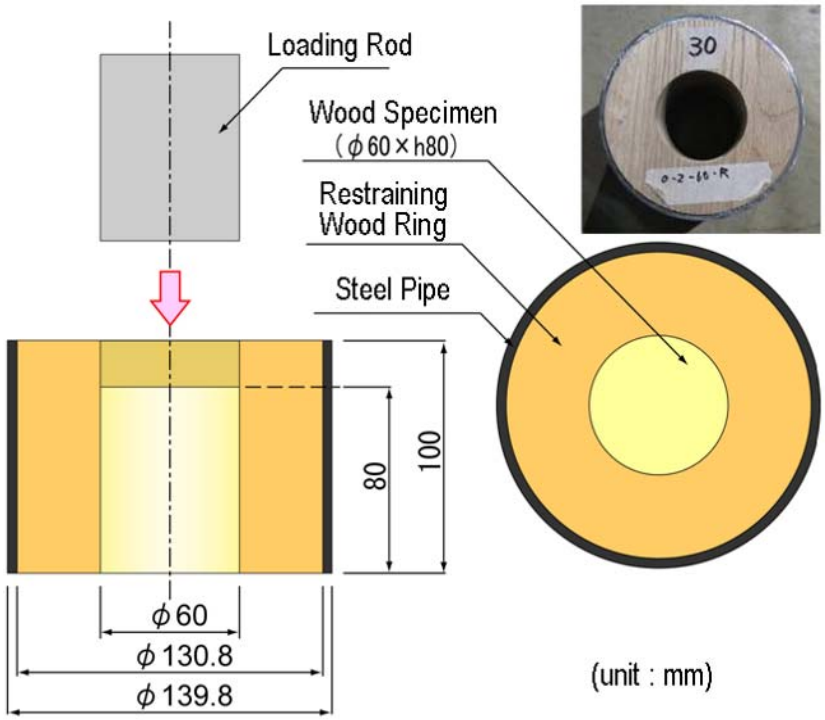


Wood Handbook, U.S. Dept. of Agriculture

- *Prepare standardized material data related to compressive properties*
  - *Static and impact crushing tests varying temperature (20, 50, 80 ℃)*
- *Investigate the affect of the temperature and strain rate effects of the wood on the impact response of the full-scale cask*
  - *Sensitivity horizontal drop analyses were performed for 9m horizontal drop test.*

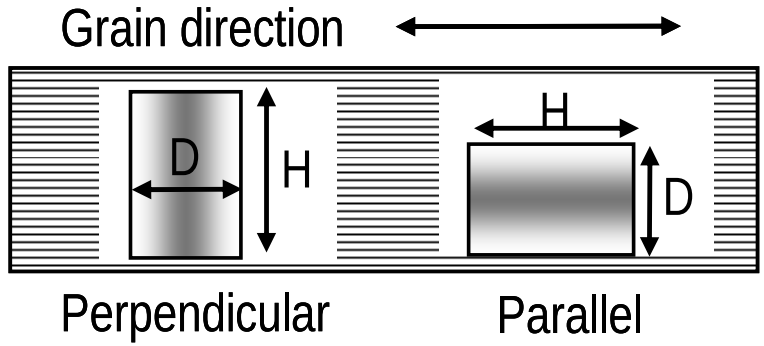
Compressive Crushing Test Method –Test Specimen-

- To obtain the compressive crushing characteristic of the wood under the constrained condition
  - Cylindrical core wood,
  - Restraining ring wood and steel pipe
- Moisture content
  - cured in the furnace at the designated temperature and relative humidity during 168 hours to control below 10%
  - 'Testing Method of wood JISZ2102-1994'
- Specimen size
  - Machined from clear-grained large block without knots and splits
  - Wood cylinder : 60mm Dia., 80mm Height
  - Wood ring : 130.8mm O.D., 80mm Height
  - Considering Locking-up strength of the wood over 50% strain and the allowable loading force of test device (Max. 500kN)



Compressive Crushing Test Method –Test Parameters-

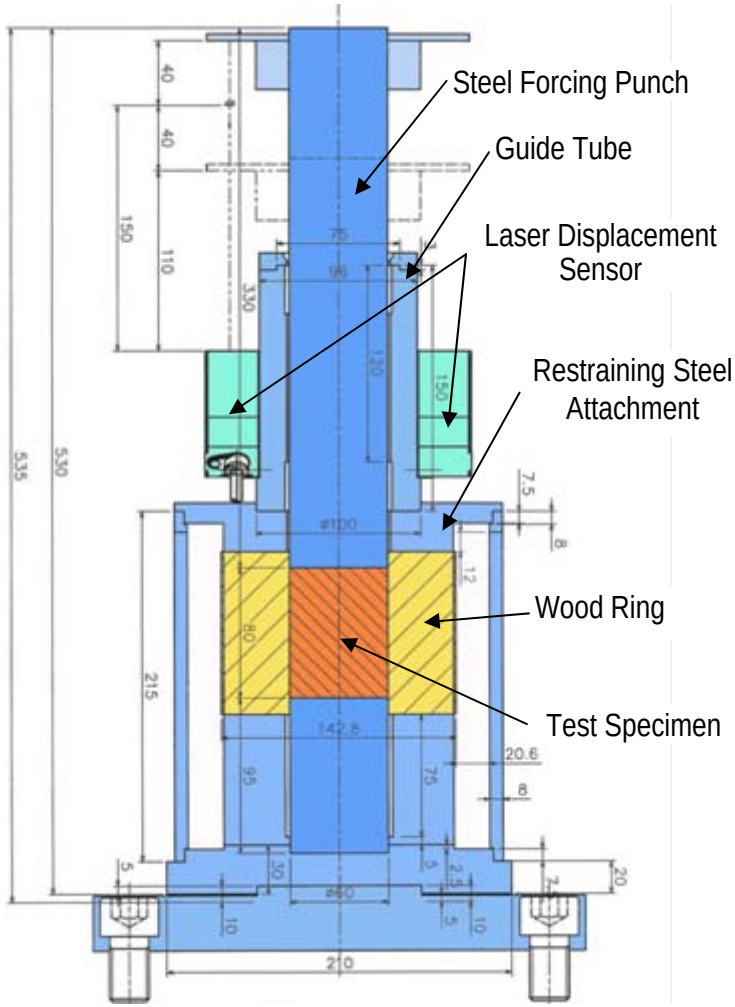
- *Wood species*
  - *Oak, Fir-Plywood, Balsa*
  - *Typical material of the shock absorber as used on the transport casks in Japan*
- *Grain direction*
  - *Orthotropic material*
  - *Two direction : Parallel to grain*
    Perpendicular to grain



- *Loading speed*
  - *0.1mm/sec (Static)*
  - *10 mm/sec (Dynamic)*
  - *1000mm/sec (Impact) equivalent to 9m drop condition*
- *Temperature*
  - *20 ℃, 50 ℃, 80 ℃*
  - *Considering allowable surface temperature limit of type B package (85 ℃)*

Compressive Crushing Test Method –Loading Device-

- *Steel forcing punch*
  - *Set in the guide tube with the bearing system*
  - *To deform the test specimen in the appropriate direction*
- *Forced displacement*
  - *Two laser displacement sensors attached to the guide tube*
- *Temperature condition*
  - *To keep the designated temperature of the test specimen during the test*
  - *Rubber heater with the thermal insulation was set around the test equipment*

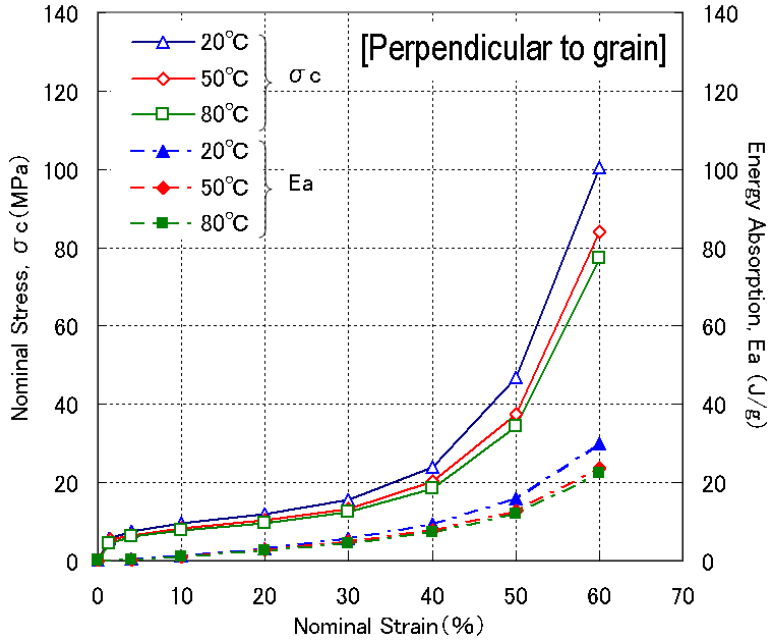


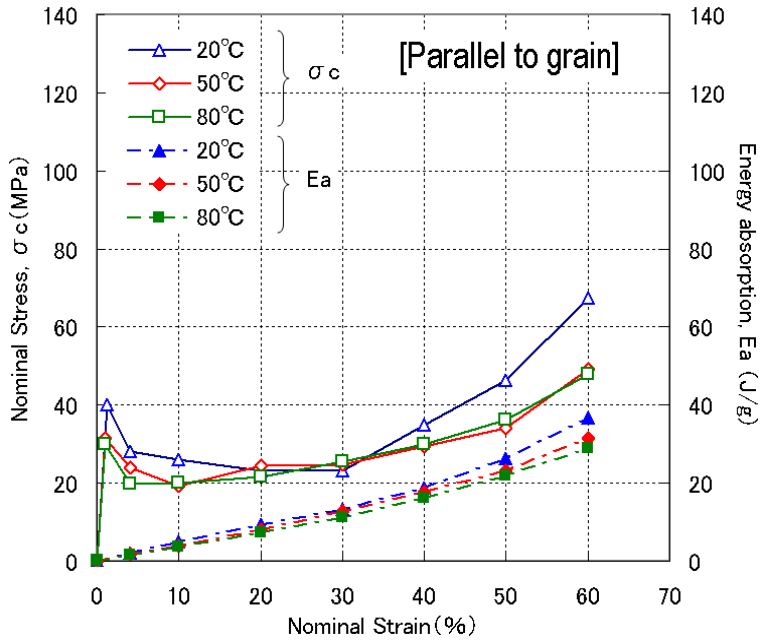
Test Results –Crushing Characteristics -

(Static Loading)		(Impact Loading)	
(Parallel)	(Perpendicular)	(Parallel)	(Perpendicular)
			
Oak		Oak	
			
Fir-Plywood		Fir-Plywood	
			
Balsa		Balsa	

Static Test Results – Fir Plywood -

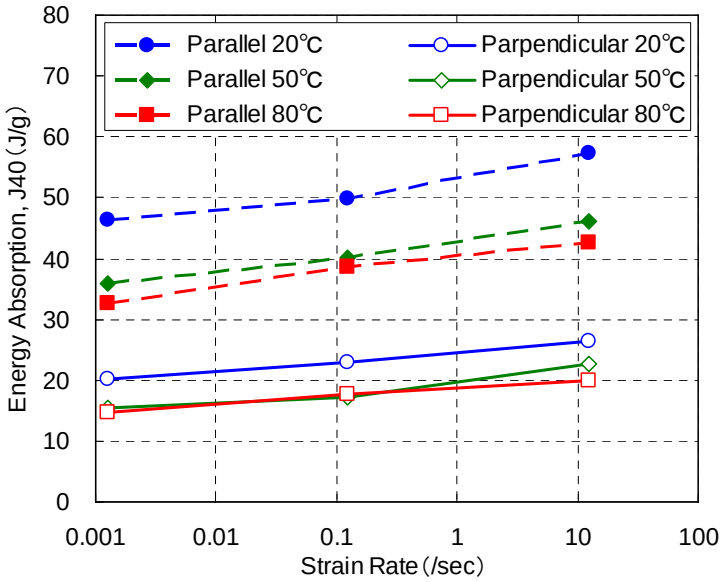
- *Static loading*
  - *Perpendicular loading orientation is typically 2 to 4 times as stiff as the parallel loading orientation at 40% strain*
  - *Specimens tested with load perpendicular to the grain*
    - *Crushed uniformly in the region below 50% strain*
    - *Rapid increase in the slope of SS curve due to the "locking-up"*
  - *Specimens tested with load parallel to the grain*
    - *buckled early in the loading process*
    - *Onset of locking-up delayed by the buckling process.*



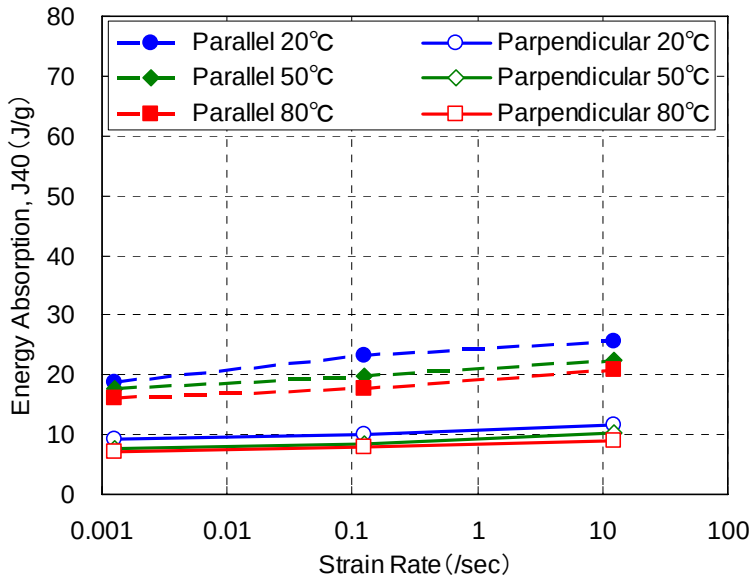


Impact Test Results

- *Crushing SS curve is very similar*
  - *Perpendicular loading orientation is also 2 to 4 times as stiff as the parallel loading orientation at 40% strain*
- *Strain rate effect*
  - *Energy absorption value up to 40% strain, J40*
  - *Impact J40 values greater than those for static ones by a factor 1.2*
- *Temperature dependence*
  - *J40 values for 80 ˚C less stiff than those for 20 ˚C by a factor of 0.7 to 0.8*



Oak



Fir-Plywood

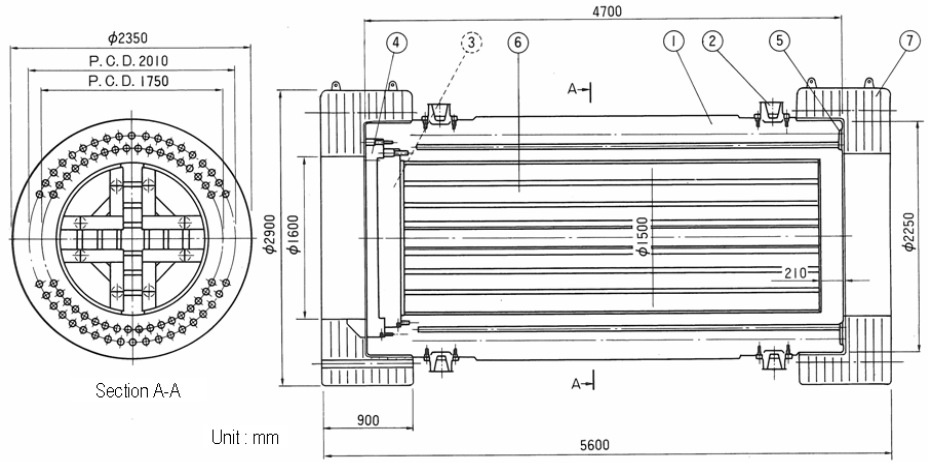
Sensitivity horizontal drop analyses –Analysis Condition-

- *Crushing test results*
  - *Temperature dependence and strain rate effect on compressive properties were found to be significant*
  - *Necessity for considering these influences on the cask design*

Sensitivity horizontal drop analyses were performed for the 9m drop test using the full-scale ductile cast iron (DCI) cask

9m drop test with DCI Cask

- *Evaluation Case*
  - *9m Horizontal drop test*
  - *Test temperature : -40 ℃*
  - *Absorbent Material : Fir-Plywood*
  - *Analysis code : LS-DYNA Ver.970*



Dimension of the full-scale DCI cask

Sensitivity horizontal drop analyses –Analysis Case-

Case #	Case 1	Case 2	Case 3
Cask	DCI Cask		
Drop condition	9m horizontal drop onto unyielding target		
Shock absorbent material	Fir-Plywood (Parallel to grain)		
Shock absorber temperature	-40˚C	20˚C	80˚C
Wood data	Static (Literature value)	Static (Material test data)	Impact (Material test data)

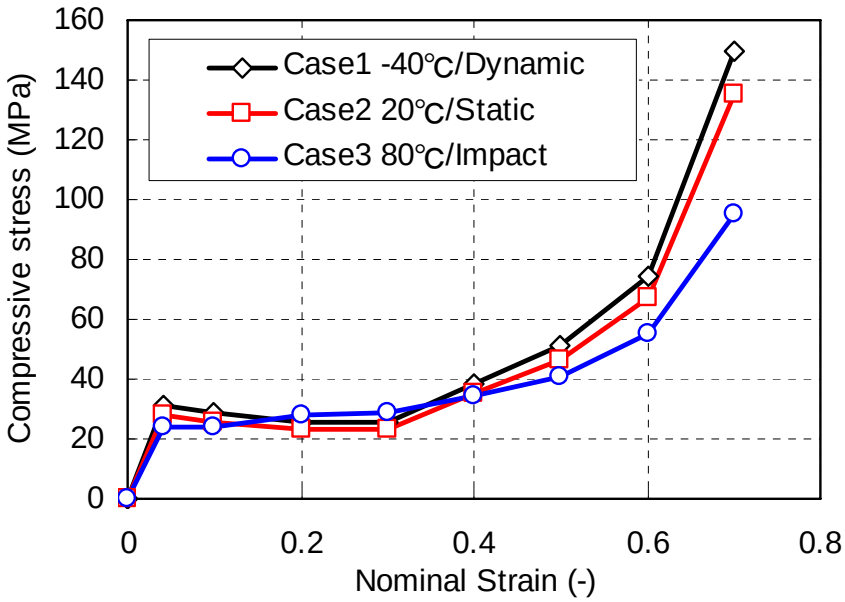
Case1 : Validate the analysis model by comparing the test results

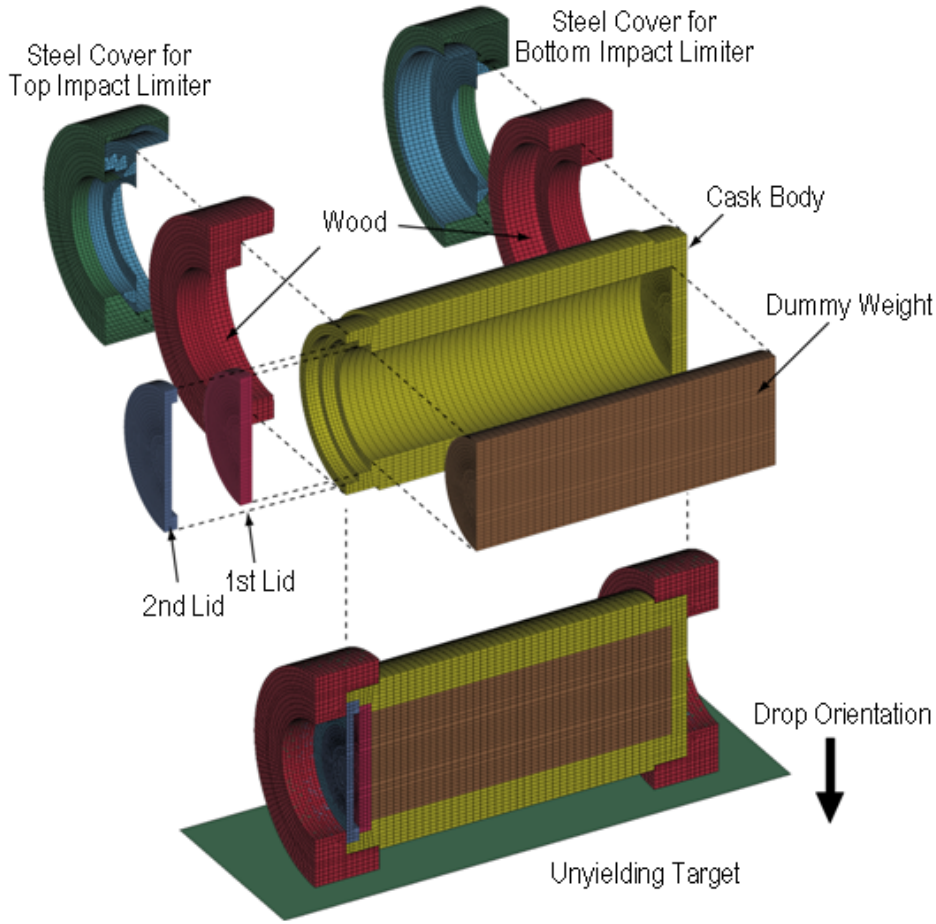
Case2 : Ordinary Drop Analysis method of transport cask

Case3 : Drop Analysis considering temperature dependence and strain rate effect

Sensitivity horizontal drop analyses -Analysis Model-

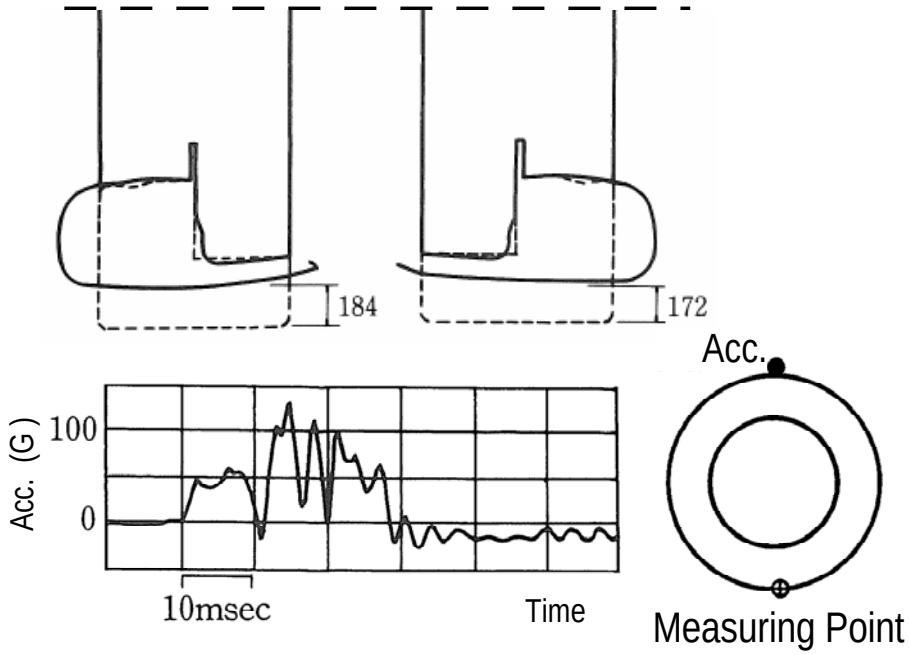
- *1/2 symmetric model*
- *Initial condition*
  - *Initial velocity 13.3m/s equivalent to the free drop velocity from 9m height*
  - *Gravity acceleration 9.8m/s^2*
- *Shock absorbent wood material*
  - *Isotropic Crushable Foam with Poisson's ratio zero (Mat type 63)*



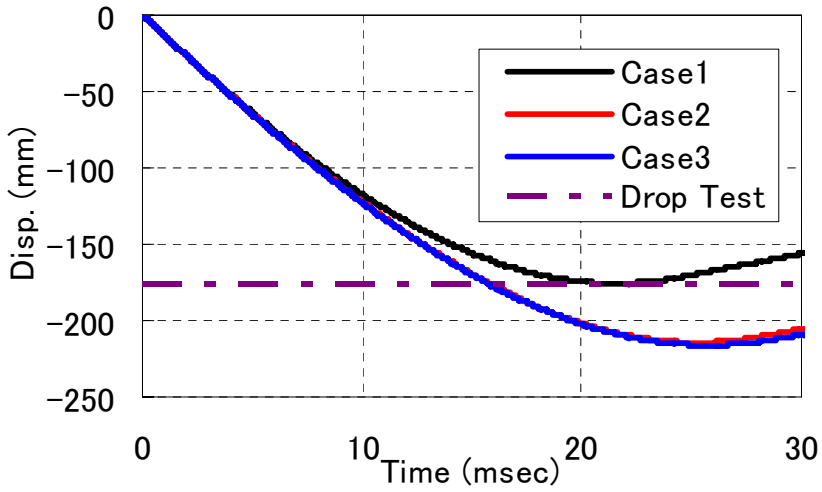


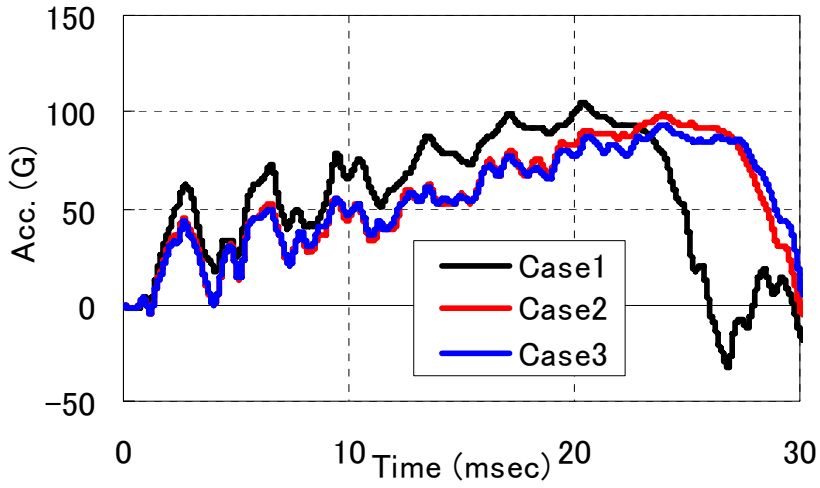
Sensitivity horizontal drop analyses -Verification-

- *Absorber deformation obtained from the drop analysis in Case1 (175mm) was almost same as that measured in the drop test (Lid: 172mm, Bottom : 184mm)*
- *Maximum acceleration was about 100G, very close to the measured value.*



Drop Test Results

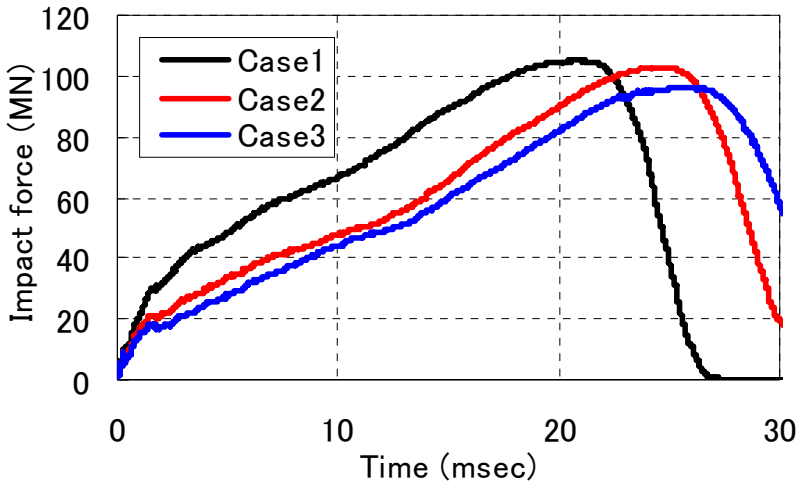


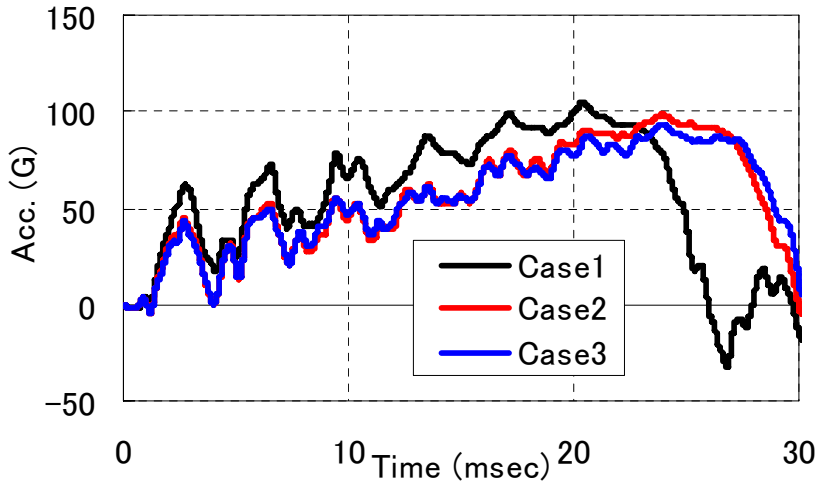


Analysis Results

Sensitivity horizontal drop analyses - Analysis Results -

- *Decrease of the energy absorption ability due to the high temperature might be cancelled by the strain rate effect.*
- *Deformation*
  - *Little difference in crush behavior between Case2 (214mm) and Case3 (216mm)*
- *Impact Force*
  - *Peak impact force for Case2 using the static data at room temperature was 103MN, those for Case3 were 96MN (only 7% decrease).*
  - *Consequently, it could be concluded that there was not remarkable difference for the stress values between Case2 and Case3.*





Conclusion

- *Compressive Crushing Test*
  Three wood species (Oak, Fir-plywood, Balsa) were selected, and data concerning temperature (20, 50, 80 ℃) and strain rate (0.001, 0.1, 10/sec) dependence on compressive properties was acquired in the static and impact tests.
- *Temperature dependence and strain rate effect*
  While the compressive strength reaches to 70-80% of that at 20 ℃ with the increase of the temperature, the impact strength increases up to 1.2 times as high as the static strength with the increase of the strain rate over 0.1/sec.
- *Influence on the impact design of the cask*
  It could be concluded that if the wood model considering the strain rate effect at the high temperature were applied to impact design of the cask, its impact behavior during the impact loading would not be significantly affected comparing the impact response using the wood model at room temperature, in which temperature dependence and strain rate effect were not considered.