Mechanical properties of corrugated boxes subjected to shocks

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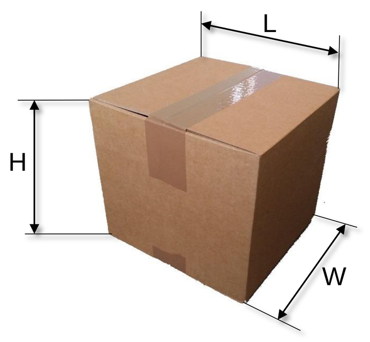
Abstract :

During a distribution cycle, the carton boxes are stacked on a pallet. The pallet is manipulated and subjected to vertical shocks. The cardboard box must resist. It must not collapse and break. Test protocols (such as ISTA) recommend shock tests on pallets. The carton must be sized to resist.

The main feature of this case is the resistance to vertical crushing (RVC). Usually, this system is studied with static method. (Constant application speed of stress about 10 mm/min). The mechanical characteristics measured are: Force at break, displacement at break, Breaking energy and Young's modulus. However, during transport, systems are subjected to dynamic loads such as shock or vibration.
The usual procedure is to determine a static RVC where an empirical coefficient is applied to estimate a dynamic RVC linked to the true transport constraints.
The purpose of this study is to understand the behavior of the cardboard material when it is constrained by shocks. Our study concerns the vertical compression strength of the cardboard box. This involves applying a compression force at different speeds. To perform the tests at high speed (> 1000 mm/min) we proceed by shock. A mass falls flat on the cardboard box. We measure the same mechanical quantities as in a static test.
The results allow us to know the dynamic characteristics of the cardboard box. The rupture energy of the body makes it possible to anticipate the falling stress that a pallet can undergo. The sizing of the transport box is thus facilitated.

Experiment :

- The tested samples are corrugated cardboard boxes, FEFCO 201 type, B flute.
- The samples are put in climate conditioning during 72 hours at 23°C – 50%RH.



Dimensions	Corrugated cardboard Box - FEFCO 201
Height (mm)	180
Width (mm)	200
Length (mm)	200
Thickness (mm)	3
Flute	B
Grammage (gr/m²)	410

Normal conditions
23 °Celsius
50 % Relative Humidity

Static compression

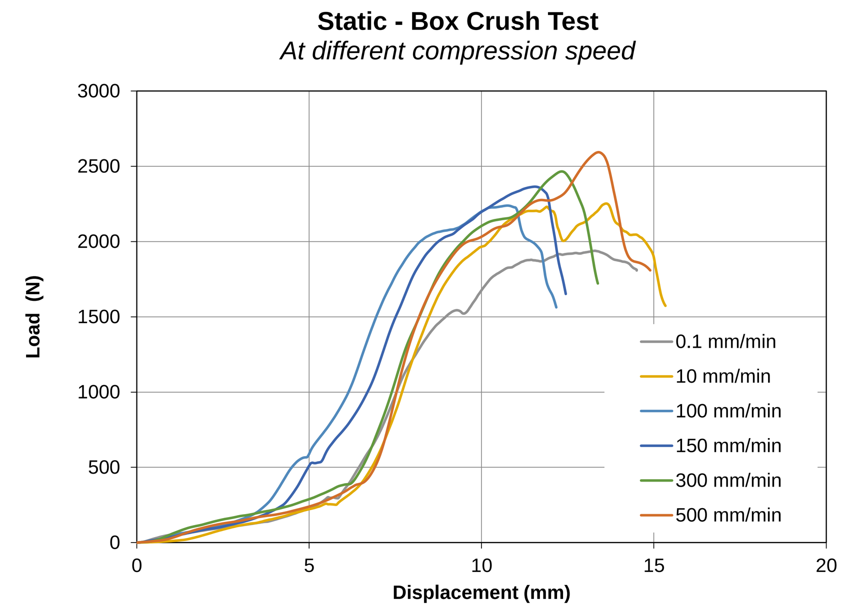
The "static" compression strength tests are carried out with an INSTRON 34204 dynamometer. The compression platen can move at a steady speed (from 0.1 to 100 mm/min). The classic and standardised test uses a compression velocity of 10mm/min.

The strength according to displacement curve is drawn.

The following results are taken from the Maximum Load, Displacement at maximum load, Energy at crush and Young modulus curves.

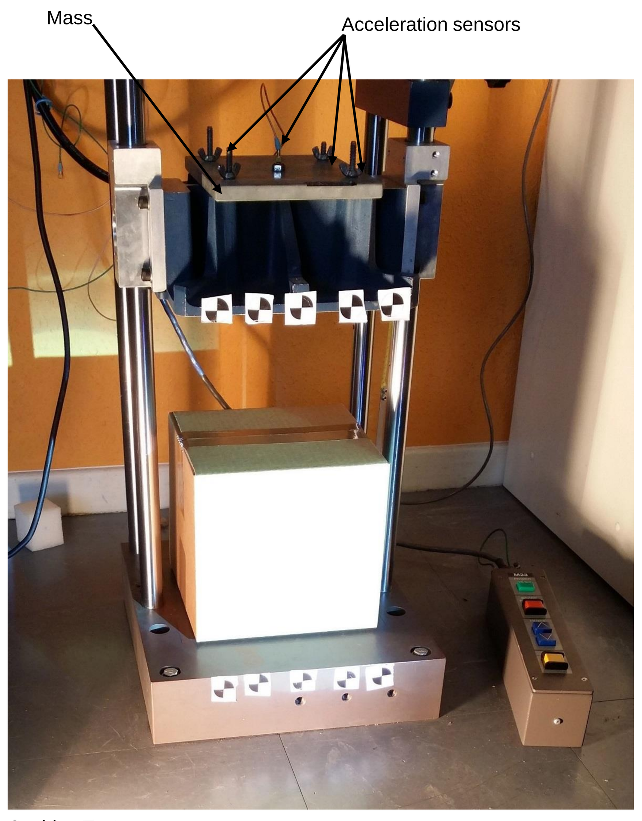
Universal Dynamometer

	Static Box Crush Test				
	Speed (mm/min)	Young modulus (MPa)	Maximum Load (N)	Displacement at maximum load (mm)	Energy at crush (J)
	0.1	1.75	1948	13.2	11.5
NF H 13-001	10.0	2.66	2262	13.6	13.1
	100.0	2.10	2249	10.7	10.6
	150.0	2.47	2374	11.5	11.4
	300.0	2.78	2476	12.3	11.7
	500.0	3.91	2604	13.4	13.8



Dynamic compression

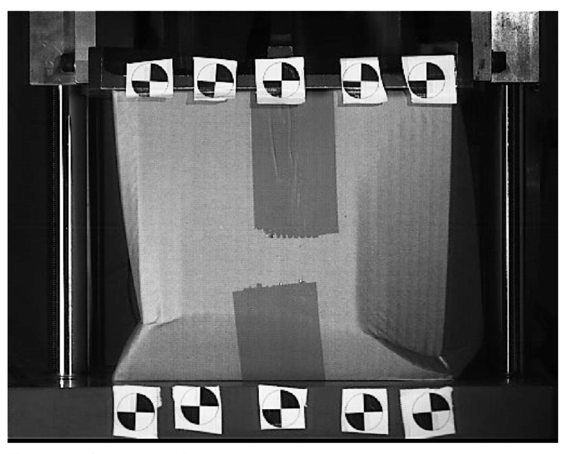
There is no machine able to carry out vertical compression strength measurements over a cardboard box with very high compression velocities. (>2,000mm/min)
Therefore, a compression experimental device has been set up. This experimental set-up is composed of a moving mass which strikes the sample after its free fall. The weight and the drop height can thus be variable. The LANSMONT Model 23 cushion tester is particularly suitable because the mass guiding system enables us to carry out a parallel platens compression.
The different weights and drop heights used for the test are listed in the table below. We then carried out dynamic compressions with velocities about 100,000 mm/min.
The compression mass is instrumented with 4 acceleration sensors. The accelerograms means is calculated. This measurement minimises the background noise and enables us to calculate the strength evolution as a function of time during the shock.
Our high-speed camera records the compression mass displacement during the shock. The i-Speed Control Pro software of our OLYMPUS i-Speed TR camera enables us to measure the compression displacement. 5 marks are tracked simultaneously.
The measurement is then possible with a resolution of 0.1mm.
The acquisition velocities of the accelerograms and of the high-speed camera photos are synchronised at 1,000 pts (or frames) per second.
You only have to synchronise the shock and displacement measures of the chosen contact point during the crushing to draw the compression curves (strength according to displacement).
The calculation of the derivative of the displacement signal as a function of time enables us to find the velocity change point (contact or impact). The curves drawn in this way are composed of about 200 pairs of points (Load-Displacement).
The following results are taken from the curves: Maximum Load, Displacement at maximum load, Energy at crush, Young modulus.



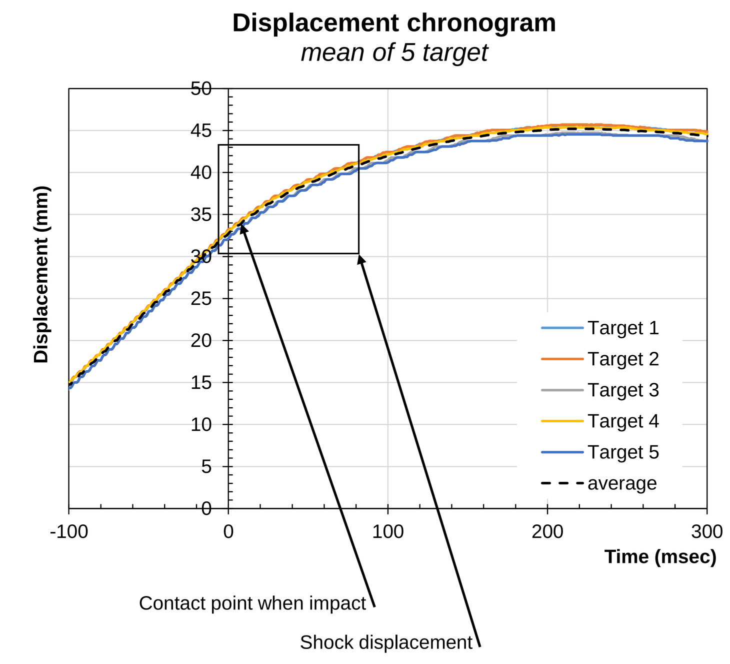
Cushion Tester

Displacement

I-speed camera



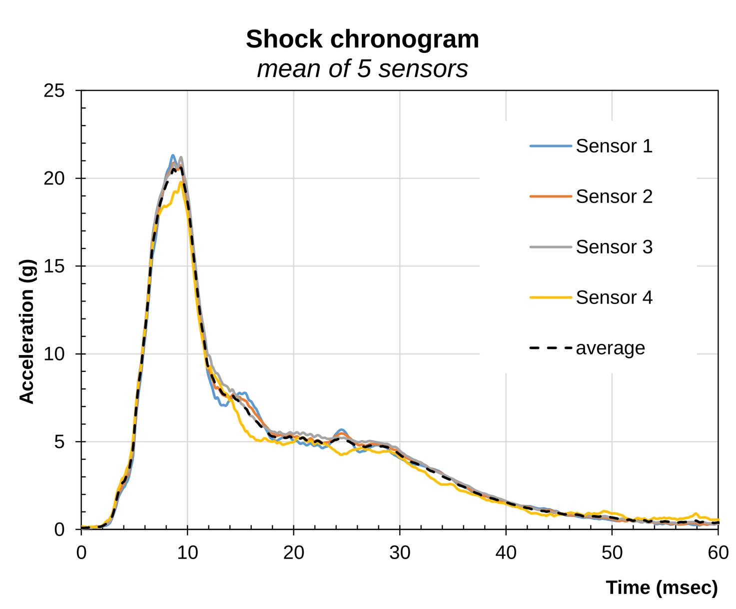
Frame traitement software

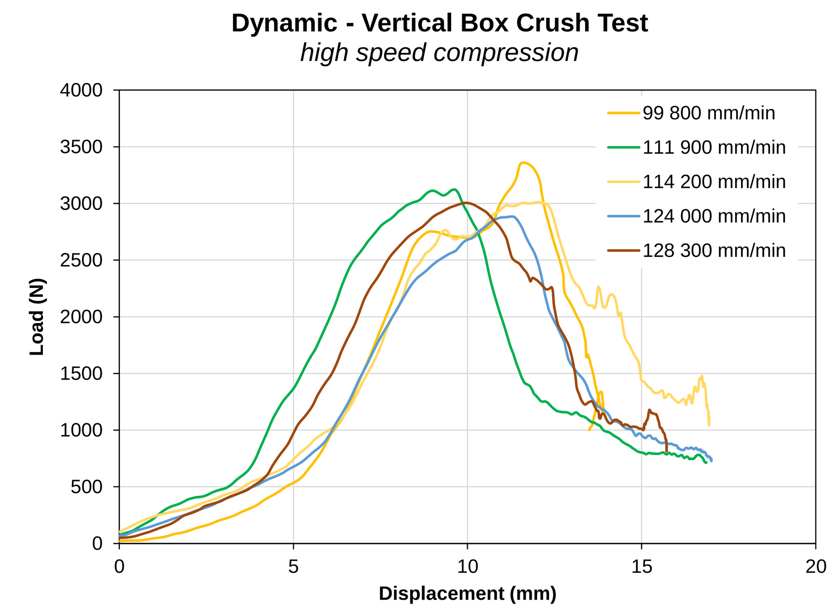


Speed (mm/min)	Shock acceleration (g)	Shock duration (ms)	Masse (Kg)	Drop height (m)
99800	19.7	16.1	17.38	0.16
111900	20.5	11.8	15.46	0.18
114200	21.2	11.7	14.48	0.19
124000	23.5	14.4	12.53	0.22
128300	26.5	11.1	11.56	0.24

Acceleration (= Load)

Acceleration sensors





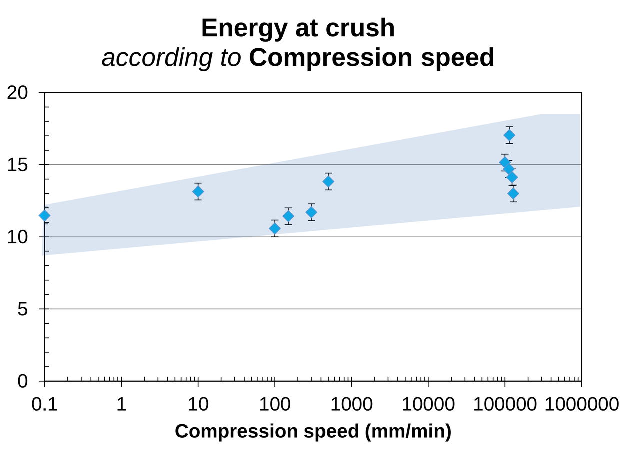
Dynamic Box Crush Test				
Speed (mm/min)	Young modulus (MPa)	Maximum Load (N)	Displacement at maximum load (mm)	Energy at crush (J)
99800	2.97	3361	11.6	15.1
111900	2.93	3122	9.6	14.7
114200	2.55	3013	12.0	17.0
124000	2.47	2884	11.2	14.1
128300	2.53	3005	9.9	13.0

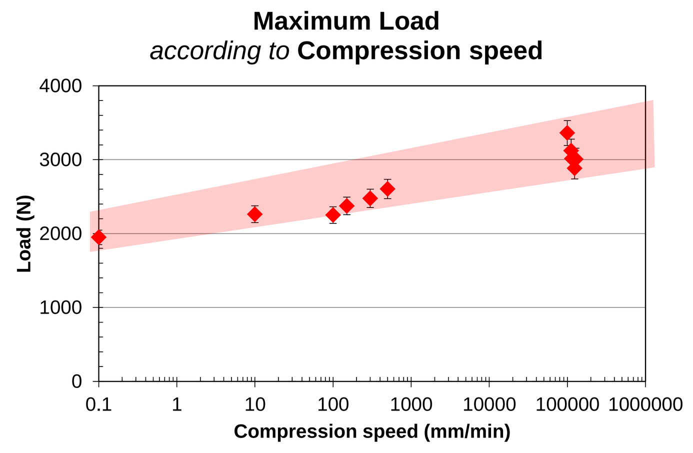
Maxi Load mean = 3006 (N)

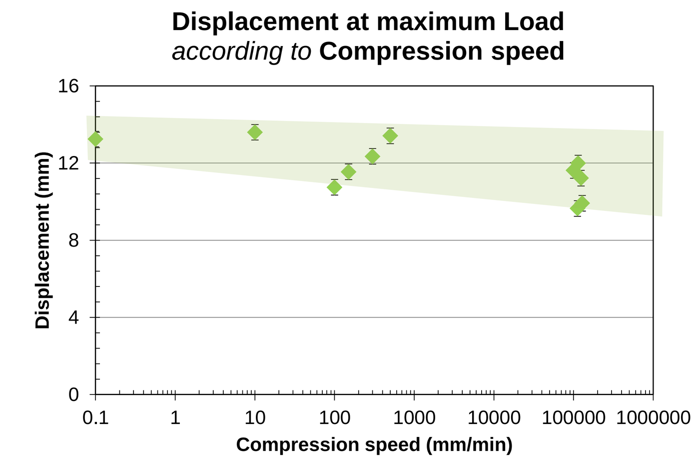
Results :

The static and dynamic vertical compression strength according to displacement (crushing) curves are similar. The curves are then comparable. The measurements distribution is linked to the lack of homogeneity of the cardboard samples.

The Maximum Load, Displacement at maximum load, Energy at crush and Young modulus measurements are represented according to compression velocity.







Conclusion :

- The compression strength (maximum load) of a cardboard box is higher if it is crushed at a high velocity.
- Therefore, when a shock occurs, a palletized cardboard box (supporting a load on the top) resists better than in static. The strength gain is about 30% compared to the NF H 13-001 static test.

- The limit deformation at which the cardboard box collapses seems to be constant.
- This deformation does not vary with the compression speed.
- These results are used in the construction of a numerical simulation model.

28th IAPRI Symposium

Conference on Packaging – Lausanne 2015 Switzerland

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