592. Investigation of Packages Resistance under Dynamic Loads

A. Kabelkaitė[1], V. Miliūnas[1], L. Gegeckienė[1], E. Kibirkštis[1], L. Ragulskis[2], V.Volkovas[3]
[1]Kaunas University of Technology, Studentų 56-350, LT-51424 Kaunas, Lithuania, tel.: (8 37) 300 237
e-mail: *asta.kabelkaite@ktu.lt, valdas.miliunas@ktu.lt, laurosius@gmail.com, edmundas.kibirkstis@ktu.lt*
[2]Vytautas Magnus University, Vileikos 8, 44404 Kaunas, Lithuania
e-mail: l.ragulskis@if.vdu.lt
[3]Technological System Diagnostic Institute, Kaunas University of Technology
Kestucio str. 27, Kaunas 3004, Lithuania; Tel/Fax:+370 7 323 720;
e-mail: vitalijus.volkovas@ktu.lt

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Abstract. Experimental tests were carried out, which led to determination of resistance of packages to free fall drop as well as resistance of plastic packages to deformation during compression under the influence of vibrations. Packages of different size and shape were used during testing. Graphic dependences of compression loads and deformations of the packages were obtained and the maximum values of compression loads and deformations after free fall drop tests were established. The obtained results and conclusions of investigations are applied for the determination of characteristics and qualities of packaging materials and packaging design.

Keywords: package, shock load, free fall, vibrations, compression, dynamic load.

Introduction

In many cases packaging is a necessary element of production process. At present, a lot of products all over the world are packed in flexible and rigid plastic packaging, since it can well protect the product against environmental impact and is relatively light, durable and cheap, but the use of the paper and cardboard in packaging as cheap and “green” material is still unabated [1,2].

Also, in recent years, the requirements for packaging productions technologies became more stringent not only in terms of design, aesthetics, but also with respect to ecological and performance criteria. This is because during distribution and transportation, the plastic and cardboard packages may be damaged by various loads. In addition to static loads, which packages carry because of stacking on one another, they can also be subjected to dynamics loads: to shock loads when falling or to vertical compression load under the influence of vibrations during the transportation [3].

A number of papers analyzing the dynamics of the packages have been published. In paper [4] the authors investigated how the pressure and vibrations influenced the leakage of the plastic and glass bottles which have the different shape and closure system. These bottles were filled with water 98% of the total volume placed in the vacuum chamber in a horizontal position, reducing pressure and causing vibrations in a manner simulating the conditions which result from the transport of cargo by air or land.

In another paper [5] the same authors also studied the effect of pressure and vibrations on leakage of different bottle/closure systems used to package dangerous chemical goods for transportation by air. The bottles were filled with water and subjected to the combined effects of random vibrations and external pressure. These bottles were placed in the vertical, horizontal and inverted orientations and observed for leaks. The results showed that vibration has an equal or greater impact than the pressure for leakage. Moreover, horizontal position of the package during the test increases the leakage of bottles in comparison to vertical position. Papers [6-8] analyzed the mechanical properties of polymeric foams used for packaging purpose under various dynamic loads.

The aim of paper [9] was to carry out tests in order to determine the effect of graphical paperboard package bottom construction and bottom dimensions on the package resistance to shock loads. The obtained results indicate that for the package edge deformations, when a package is dropped onto the bottom plane, the drop height has no effect. When a package falls onto the long edge, the deformation of this edge increases with larger drop height. Height had the greatest impact on the package when the package fell onto the short bottom edge when 67% of tested packages bottom broke.

Other authors [10, 11] also studied the effect of the shape of the protective packaging materials inside a corrugated paperboard box on the loads caused by falling shocks. During the tests it was observed how many goods were damaged, or the deformations or cracks were measured, or visual assessment was performed according to relevant criteria.

In summarizing the performed study analysis, it may be stated that in most of the publications the study object is the performance properties of the plastic and paperboard packages under the influence of dynamics loads. So the aim of the present study is to carry out tests in order to determine the effect of size and different shape of package on it resistance to shock loads and compression loads under the influence of vibrations.

Experimental equipment and method

The experimental study was carried out by using different samples (plastic containers) which have truncated-cone-shape, tapered downwards. The samples were made from polystyrene (PS) and polypropylene (PP), whose exterior view is presented in Fig. 1. The volume of PP packages was – 400 ml, and of PS type packages – 420 ml.

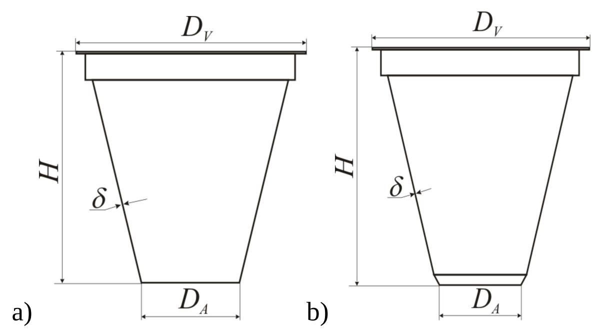

Fig. 1. Types of packages and their specimens with characteristics used for the test: a) – polypropylene (H – 115 mm; D_v – 95 mm; D_A – 64 mm; δ – 0.21 mm; E = 1.5 GPa ; ν = 0.43); b) – polystyrene (H – 120 mm; D_v – 95 mm; D_A – 65 mm; δ – 0.23 mm; E = 2.3 GPa; ν = 0.38).

For the evaluation of mechanical properties of plastic packages the designed compression setup was used, which simplified scheme is presented in Fig. 2.

Empty unfilled plastic package *9* was placed on the vibration stand plate *4* and the top of the package was compressed by a top plate *3*, which could move only in vertical direction and was approved by a static load of 6 kg. The aim was to simulate the transportation of packages, when the packages are loaded on pallets which, in their turn, are stacked one upon another. Therefore a static mass of 6 kg was placed on the top plate *3*. Distance *1* and acceleration *2* sensors record the displacement of plate *3*.

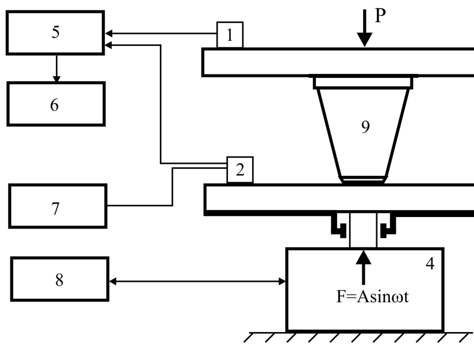

Fig. 2. A simplified scheme of experimental setup for testing package compression under the influence of vibrations: 1 – inductive distance sensor „IFM Electronics IG6084“ (2 pcs.), 2 – acceleration sensor „VEB Metra KD35“ (2 pcs.), 3 – top plate, 4 – vibration generator „TIRAvib 50300“, 5 – oscilloscope „PicoScope 3424“, 6 – personal computer, 7 – DC power source for distance sensors „Б5-49“, 8 – low frequency vibration generator “Г6-27“ and the control unit of vibration generator „TIRAvib 50300“, 9 – package under compression.

Distance and acceleration sensors have been connected to 4-channel oscilloscope *5*, which was connected to a computer *6*. The tests data were recorded with the help of computer software “PicoLog Recorder”.

Low-frequency generator produced sinusoidal vibrations, which frequency was fixed to 20 Hz and 30 Hz during testing. In control unit *8* the required vibration amplitude was determined, which later was increased gradually until the plastic package began to deform and reached the stage of plastic deformation. After that, the experiment was stopped.

For the test of the package resistance to falling shock loads we used multilayered packages, which consist of paper, plastic and aluminium foil (Fig. 3).

The volume of packages used for the tests was 0.5 l, 1 l and 2 l. These types of packages are widely used for various beverage packaging.

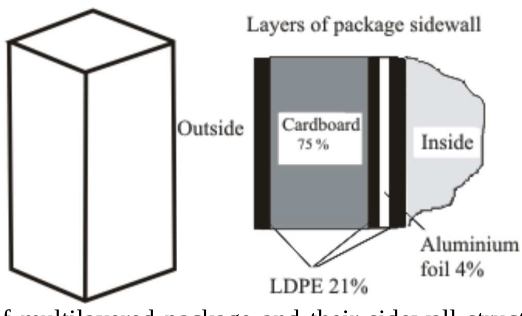

Fig. 3. General view of multilayered package and their sidewall structure with characteristics (cardboard - ν_{MD}=0.37; ν_{CD}=0.12, E_{MD}=5.6GPa; E_{CD}=2.0 GPa; LDPE - ν=0.49, E= 0.1-03 GPa and aluminium foil - ν=0.33; E=70 GPa)

During the test, the multilayered package was fixed with the thread in a special stand, and then it fell onto a solid surface, which was connected to a shock load sensor. Subsequently, the shock load signal was transformed into a digital form and the test results were processed with the help of personal computer (see Fig. 4). The tests of plastic and multilayered packages were carried out at the temperature 20±2° C and air humidity 65± 2%.

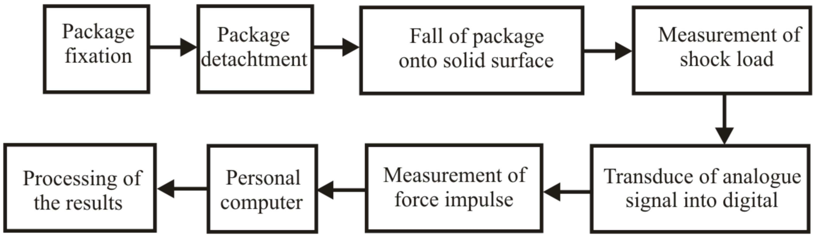

Fig. 4. Block scheme of the test sequence

Results and discussion

Fig. 5 presents the dependencies of deformation – compression dynamic loads of PP-type plastic packages under the influence of vibrations. Variation character of obtained curves is similar at 20 Hz and 30 Hz frequency. Increase of dynamic loads of compressing top plate leads to larger deformation of packages.

It was established that the maximum dynamic compression load at 20 Hz frequency is 62.76 N and at 30 Hz – 61.29 N. So it can be claimed that the increase of frequency does not significantly affect the inertia load. However, at higher frequencies the packages undergo higher plastic deformations (about 2mm at 20 Hz and about 2.5 mm at 30 Hz). As mentioned previously, the experiment was stopped when the package reached the state of plastic deformation, so the deformations are not so significant. But these deformations are essential, because under influence of vibrations and static load, the packages loose their rigidity and deform (become unsuitable for further usage).

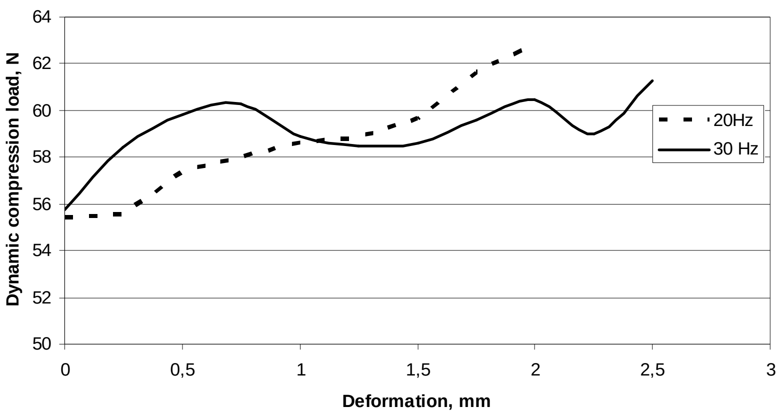

Fig. 5. Resistance to compression under the influence of vibrations of PP-type plastic packages

Fig. 6 presents the dependencies of deformation – compression dynamic loads of PS-type plastic packages under the influence of vibrations As well as in the case of PP-type packages, the change of deformation – compression dynamic loads curves of PS-type packages is similar.

The maximum compression dynamic load at 20 Hz frequency is 62.33 N and at 30 Hz frequency – 65.87 N. Similarly, the PS-type plastic package at 30 Hz frequency undergoes higher plastic deformations (about 2.25 mm at 20 Hz and about 3 mm at 30 Hz).

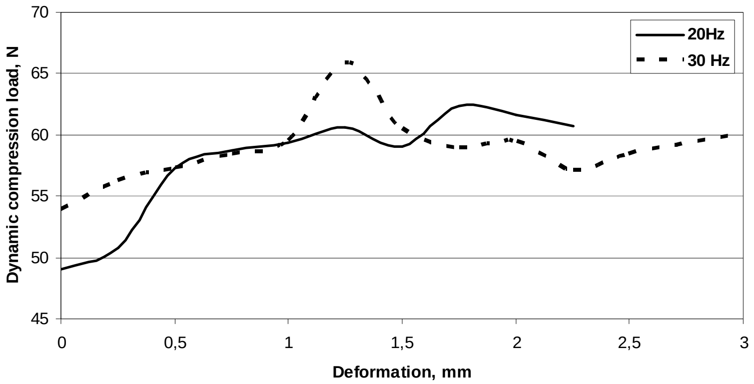

Fig. 6. Resistance to compression under the influence of vibrations of PS-type plastic packages

After several tests, when the multilayered package falls from 2 m height, it was obtained that the all packages were broken through adhesive joints of package sidewalls. So the fall heights were limited to only 0.5 m and 1 m.

According to the experimental results, the fall from 0.5 m and 1 m height onto the plane solid surface for 0.5 l and 1 l packages does not significantly affect the resistance to shock loads. When packages fall from 1 m height: $\approx 1\cdot 10^{-3}$ m for 0.5 l package, $\approx 2\cdot 10^{-3}$ m for 1 l package, and when packages fall from 0.5 m height: $\approx 2\cdot 10^{-3}$ m for 0.5 l package and $\approx 1\cdot 10^{-3}$ m for 1 l package. So it can be stated that when the packages fall from 0.5 m and 1 m height onto the plane, the deformations of edges are marginal.

The fall from 0.5 m and 1 m height of 1 l and 2 l packages onto the edge (45° angle) also does not significantly affect the resistance to shock loads, because the deformations of edges are even smaller as mentioned above. After the tests these packages could be used further. But the fall from 0.5 m and 1 m height onto the edge is the most dangerous for the 0.5 l package, because it becomes no longer suitable for further usage.

Experimental results allow to make an assumption that the fall of package onto the plane solid surface is more dangerous in comparison to the fall onto the edge (for example: the shock load when 2 l package falls from 1 m height onto the plane is ~ 1.26 kN and onto the edge ~ 890 N (Fig. 6)).

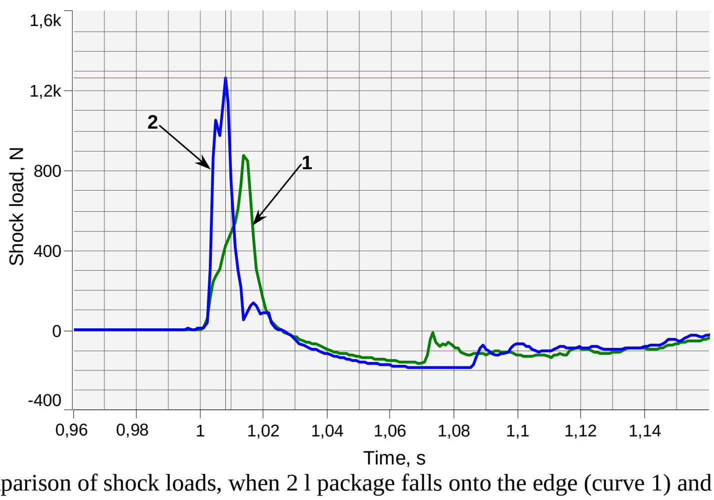

Fig. 7. The comparison of shock loads, when 2 l package falls onto the edge (curve 1) and onto the plane (curve 2)

Conclusions

1. Maximum values of compression dynamic load of plastic packages, which have truncated-cone-shape, tapered downwards and were made from different materials, have been determined. For PP-type package – 62.76 N at 20 Hz and 61.29 N at 30 Hz. For PS-type package – 62.33 N and 65.87 N respectively.
2. Both types of tested plastic packages deformed more at 30 Hz frequency than at 20 Hz.
3. Experiment results demonstrate that the resistance of multilayered package to shock loads highly depends both on fall angle and height. The fall of the tested packages onto the plane is more dangerous than the fall onto the edge.
4. The highest fall height was determined. When multilayered package (0.5 l, 1 l, 2 l) falls from 2 m height it cracks through the adhesive joints of sidewalls and becomes unsuitable for further use.
5. The obtained testing results can be applied in design of packages as well as for evaluation of their transportation conditions while preserving the desired level of package function.

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