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DEFINE CUSHION CURVES FOR ENVIRONMENTAL FIRENDLY PACKAGING FOAM

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ABSTRACT: *In this paper, we wrote about that packaging foam, which can be a critical component in the defense against the logistic stresses. The continuous developing of the materials gives us the possibility to apply new and possible environmental friendly packaging (EFP) materials. To apply these materials in practice we have to know many attributions for example its cushion characteristic. We investigate a possible predicting to make easier its testing method in the development process.*
KEYWORDS: *cushion curves, environmental friendly packaging (EFP), packaging development*

INTRODUCTION

If we examine a product and its packaging system, we confront with many important questions. In this article, we write about that segment which could be a critical element in the application of cushion materials. This problem is the constructing and designing the cushioning system. Predicting and choosing the suitable material quality and the needed thickness for the product, works well in the field of common synthetic polymers, but we don't know how it works with EFP cushions.

However, the synthetic polymers fulfill the cushioning function, the environmental aspects stronger and stronger in the designing of packaging systems. So analyzing the Life – cycle of these materials, we will get a not so positive picture. The balance of benefits and disadvantages are continuously changing and the problematic questions of the packaging waste problem grow the group of negative parameters. To solve the littering problems, the possible application of environmental friendly foams, are going to be more-more important. To substitute these common plastics, we have to know many parameters [1].

In the first half of the article we define that basic information in the field of biodegradable materials which we have to know. These terminus – techniques' are quite new definitions in the field of industrial packaging. We also define those parameters which we have to know about the cushion dynamics.

In the second part we implement a predicting methodology for giving a cushion curve of an environmental friendly and biodegradable cushion material. This progressive analysis based methodology works well in the filed of synthetic foams.

CUSHIONS IN THE FIELD OF PACKAGING

If we investigate the packaging applications in the logistics, we can easily find that large amounts and varied plastics are used as packaging material, see figure 1 below. From the total, the foams means cc 10% a s weight, but it is reasonable that it is a very huge volume. So these industrial applied plastic foams highly grow the packaging waste volume.

In the initial situation, when a new packaging system is developed, the engineers tent to be over the applied packaging material's life cycle. The cost only counted about the direct costs and they overlooking about the waste costs and other important costs. The false developed system will show disadvantageous quantitative and qualitative facts and parameters.

Well known example for this kind of development, when the logistic environment had defined regardless, this caused product damage. The average answer for this problem is the overpacking (for example with extra or higher density foams), which cause extra costs and additionally won't solve the product damage problems.

On a rough estimate ten years ago, the common synthetics plastics, based on petrochemicals, had got more and more focus, because as the prices, as the regulations became higher and more severe. To solve these problems, the material science is going to get a solution for the packaging engineers. The *new environmental friendly materials possible are able to pass those requirements, which defined by environmental and packaging standards and regulations. The groups of the applicable materials which can substitute synthetic foams are continuously changing, as the investigation, test and development of these materials and publicized by other writers.*

The following table is well illustrating those materials, which are going to get higher focus in the field of industrial packaging development [2].

Biodegradability

Fully biodegradable	- PBS - PBSL - PCL - PTMAT - etc...	- Stretch blends (with bio-degradable fossil-based copolymers) - PLA blends (with biodegradable fossil-based copolymers)	- TPS - Stretch blends (with bio-based and bio-degradable copolymers) - PLA - PHA - Cellulose acetate - Regenerated cellulose
Non- biodegradable	- PE - PP - PET - PVC - PUR - ABS - etc...	- Starch blends (with polyolefin) - PA 610 - PET from bio-based ethylene - PUR from bio-based polyol - etc...	- Bio-based PE - PA 11 - Bio-based PB
	Fully fossil-based	**Partially Bio-based**	**Fully bio-based**

Biobased raw material

Figure 1 - Current and emerging bio-based plastics and their biodegradability

To understand the processes and tendencies of environmental friendly foams, we have to clearly define those terms, which appears in the field of any kind of degradability. The following flowchart well illustrates the simplified process of degradation.

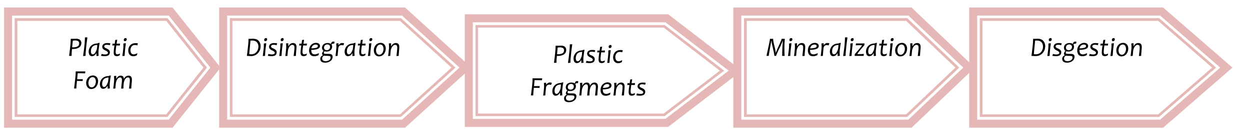

Figure 2 - The schematic figure, of a degradation process (source: authors)

There are many papers, which are well defined the details of these processes, so we don't write the details of the process [3] [7]. Additionally we only cite some important terms:

- *Biodegradable: Capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardized tests, in a specified period of time, reflecting available disposal condition [4]. Potential of a material to be degraded which is caused by biological activity especially by enzymatic action leading to a significant change of the chemical structure of the material [5].*
- *Compostable: Degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leave no visually distinguishable or toxic residues [4], [6].*
- *Degradation: An irreversible process leading to a significant change of the structure of a material, typically characterized by a loss of properties (e.g. integrity, molecular weight, structure or mechanical strength) and/or fragmentation. Degradation is affected by environmental conditions and proceeds over a period of time comprising one or more steps [4], [5], [6].*
- *Disintegrating: the falling apart into very small fragments of packaging or packaging materials, it is caused by a combination of degradation mechanisms. [4], [5], [6].*

On the following figures, the cross-section of 3 type of cushion material can be seen.

Sample 1. *Sample 2.* *Sample 3.*

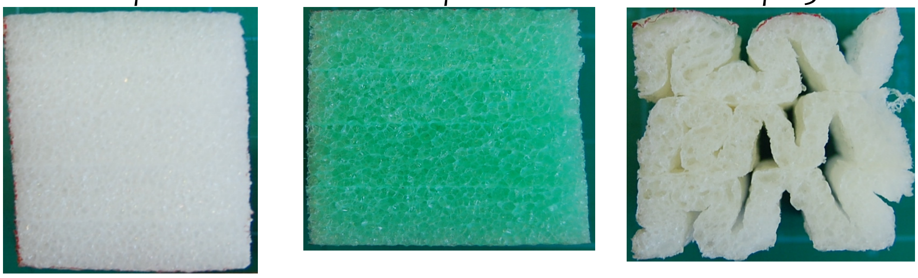

Figure 3 - 3 type of foam, applied as a cushion material (source: authors)

1. *Normal PE foam with 35 kg/m^3 density, (from only one layer). The solutions if the material became waste are the followings: recycling after sorting or the energetic utilization. Open-cell foam.*
2. *Multilayered PE foam (35 kg/m^3 density) with additive, which can accelerate the degradation process of the material. Open-cell foam.*
3. *Starch based, and multilayered waveform foam (33 kg/m^3 density). The construction is based on absolutely natural materials, so it becomes biomass as a packaging waste. Closed-cell foam. [8]*

The second part of this paper, we introduce the basic background of the cushioning and investigate the adoptability of a new type predicting methodology for an environmental friendly cushioning.

METHODOLOGY TO PREDICT THE DYNAMIC CHARACTERISTICS

A mechanical shock or impact occurs, when and the packaged products' position, velocity or acceleration suddenly changes. A shock may be characterized by a rapid increase of acceleration (x) followed by a rapid decrease over a very short time (t). During the logistic link it can appear as a dropping, throwing and other abuses caused by the manual loading, unloading and handling of packages. The figure 4 is made by Hottinger-Baldwin Spider 8 measurement system with software catman professional.

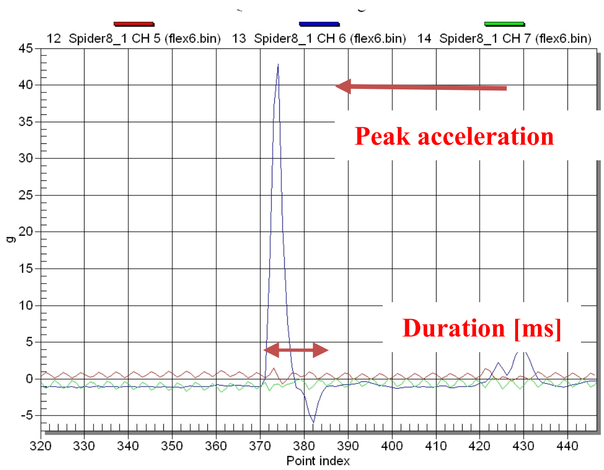

Figure 4 - Registered shock during a drop on a packaged product

In the cushioned packaging system, surely the cushions' aim to decrease and decelerate these critical values, as it possible.

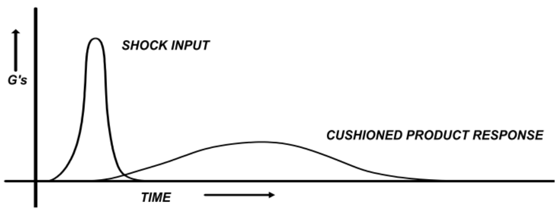

Figure 5 - Idealized shock input and cushioned response (source: Pánczél et al. 2005)

To make the right and suitable decision about the possible application cushion material, we know much mathematical coherence and we have some initial information about the material. One of the most important things in these cases is the cushion curve of the materials.

Cushion curves are graphical representations of a foam material's ability to limit transmission of shock (called G level) to a product. G level is plotted along the vertical axis versus static loading (weight divided by bearing area) along the horizontal axis. Curves are specific to a particular material, a particular density, and a particular drop height. Simply consulting the cushion curve will visually tell how many G's will be transmitted for a given drop height, cushion thickness and static loading [9]. This process was worked out for giving the cushion curves of a normal packaging material.

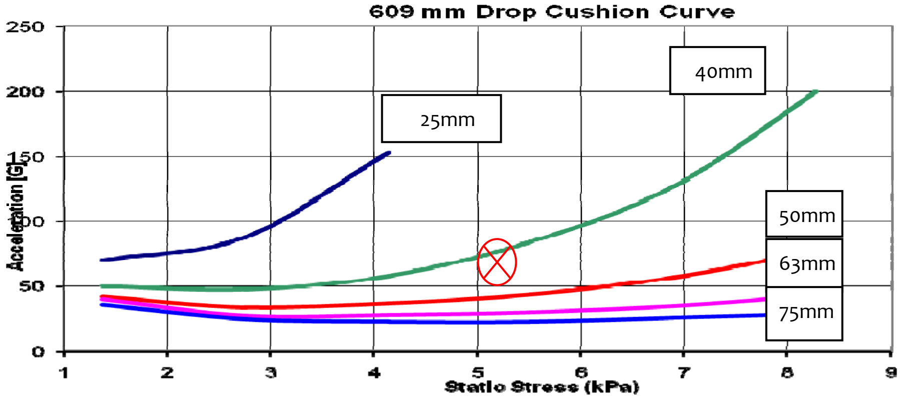

Figure 6 - The cushion characteristic of an environmental friendly cushion (cc40 mm thick material at 5 kPa static stress, with 73 g)

This method for constructing cushion curves is based on standardized procedure, on standard temperature (25 Celsius), and 55% relative humidity. It is possible to overcome the limitation of selected data, but the process for collecting this information is very time consuming and resource intensive. To generate a full set of cushion curves (range of drop heights, about seven cushion thicknesses) would require somewhere on the order of 10,500 sample drops and over 175 hours of test time. Even more samples and time would be required to fill in the data for other cushion thicknesses and drop heights [9], [10].

THE CUSHION CURVE OF "EFP" MATERIALS

There can be a possible way if we want to simplify the process of generating cushion curves, and to give the ability to generate an unlimited number of curves with any set of variables (i.e. any drop height, any thickness, any static loading). This method is based on dynamic stress versus dynamic energy. This method is to realize material properties of a cushion can be described by a relationship between the specific variables of static loading, drop height, cushion thickness and G level. These are very familiar conditions which are used in traditional cushion curves, and with Daum's work (Daum 2006), which is applied for the normal and open-cell packaging foams. Instead of testing all variables to draw cushion curves we can reduce all combinations of drop height, static loading and thickness into a single equation that is able to generate any cushion curve we would like for given specific EFP material or closed-cell foam.

*The dynamic stress can be defined in G * s (G times static loading), and the dynamic energy can be defined as s*h/t (static loading times drop height divided by cushion thickness).Both of them have units of Pascal (kPa).*

*This method says that for any calculated energy, G can be predicted. If we want to compare predicted G levels (from G*s) to actual G levels from the published cushion curve in different combinations of s, (h) and (t) , (G) levels can be predicted very accurately.*

- *First step. You have to set the maximum and minimum limits on the energy absorbed. Because of energy = sh/t, the minimum energy corresponds to the smallest s, the smallest h, and the largest t that you want data for. The maximum energy corresponds to the largest s, the largest h, and the smallest t that you want data for.*
- *Second step. Divide the energy range in step first into about 5-10 approximately evenly spaced points. If the range 5 to 100kPa is used, then test for energies in steps of about 20 kPa. You could for example choose 9 different energies equal to 20, 40, 60 . . . . . and 100kPa.*
- *Third step. For each of the energies chosen in second step, select five-six different combinations of (s), (h) and (t) values that give this energy. In this example these are 6 combinations listed in the range in second step. For example, six different combinations of (s), (h) and (t) that give sh/t = 20 are:*

Table 1 - Variables for calculating dynamic energy

Static loading s (kPa)	Height h (mm)	Thickness t (mm)	Dynamic energy (kPa)
1	400	20	20
2	300	30	20
3	200	30	20
4	200	40	20
5	120	30	20
6	33	10	20

Next, we have to perform these 6 drops on the cushion tester (or drop tester). For the first drop, we can set the cushion tester up for an equivalent free fall drop height of 400 millimeters, and we can select a cushion sample with an actual thickness of 10 mm. We have to add enough weight to the platen to achieve a static stress of 1 kPa, and drop the platen. The shock pulse can be captured the peak acceleration (G) by recording machine (in this way we use HBM - Spider 8). These have to be completed for the six drops corresponding to energy of 20 kPa. Now we can summarize the experimental data in a table like table 2. The G values in the 4th column come from the drop tests. Sample numbers are used for illustration purposes. The last column of this table shows the calculated stress values corresponding to energy of 20 kPa.

Table 2 - The calculated and performed G's level in dynamic energy of 20 kPa

Static loading s (kPa)	Height h (mm)	Thickness t (mm)	Measured G's G (g)	Dynamic energy s*h/t (kPa)	Stress = G*s (kPa)	Average (kPa)
1	400	20	68,5	20	64,5	70,1
2	300	30	37,5	20	75	
3	200	30	26,8	20	80,4	
4	200	40	17,9	20	71,6	
5	120	30	13,5	20	67,5	
6	33	10	9,8	20	58,8	

The mean in this case is 70,1 kPa and the standard deviation is 3.67 kPa, which is 5.2% of the mean.

- *Fourth Step. Repeat step third for each of the energies (doing on the six levels of the total range of 20 – 100 kPa) in the range chosen in second step and construct the stress vs. energy relationship shown below. The stress values listed are the means for the 5 replicates tested for each energy. The variations are the standard deviations expressed as a percent of the mean. Sample numbers are used for illustration purposes.*

Table 3 - The calculated acceleration (G) on each static loading for a given material

Dynamic energy (kPa)	G's (g)	Variation in percent (%)
20	70,1	5,65%
40	106,18	1,81%
60	127,58	4,28%
80	316,45	7,11%
100	785,56	6,07%

- *Fifth step (optional). Fit an equation to the stress (G) vs. energy data. The relationship between stress and energy can usually be described to a high degree of correlation by the exponential relationship:*

stress = a eb(energy),

where (a,b) = constants specific to foam type and density and (e = 2,71 constant)

This regression can be used to best fit this equation to the data. The next step is to plot dynamic stress versus dynamic energy, and apply a simple exponential curve fit to the data points (Power Trend-line in Excel), as shown in Figure 8.

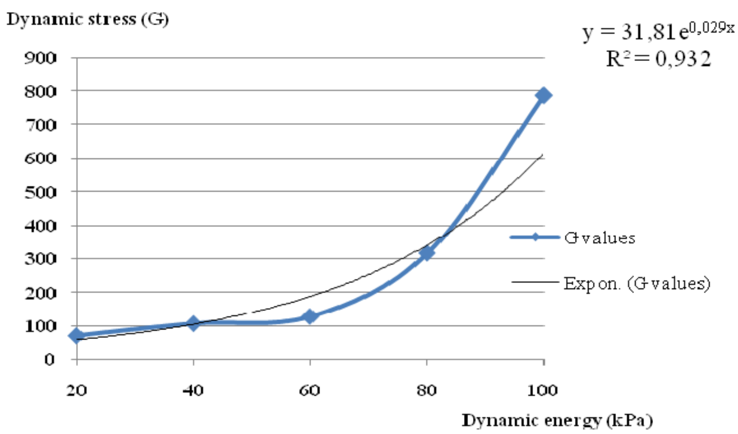

Figure 8 - Dynamic stress versus dynamic energy

Using the Stress-Energy Equation to Generate Cushion Curves. A simple spreadsheet can be set up to use stress equation to draw any cushion curve for a given material. An example is shown in Figure 8. Now we can simply change the drop height and/or thickness and plot G versus static loading (s).

The equation is now the Dynamic Stress-Energy equation that fully describes the cushioning ability of a given material. Also, this graph displays R2 value, which is an indication of how well the equation fits the data. The 93% percent is extremely good. The equation shows the value for (a) is 31.81 and the value for (b) is 0.029. Now we have one equation that can be used to generate for any cushion curve for this material.

Notice: The detailed parameters and the test results are archived by the authors.

CONCLUSIONS

The consequence is that, we are able to use this method to test and deterimne the cusion characteristic of environmental friendly packaging materials and closed-cell packaging foam as well. It can help us to apply these materials in practice as soon as possible. This method has already been familiar, because it is used by giving traditional cushion curves, but instead of testing all variables to draw cushion curves we can reduce all combinations of drop height, static loading and thickness into a single equation that is able to generate any cushion curve we would like for given specific material.

We had got the same results as we have found in other publications, which deal with the cushion curve in the field of normal (open-cell) packaging foams (like Daums's work). The calculation shows that the cushion curve correlation was excellent across all number of drops, almost always over 90% and in many cases over 95%.

Since the stress-energy method relies heavily on energy absorption (static loading, drop height, thickness), great care needs to be taken when measuring these variables. By this method we do not have to test each variables of a given material (i.e. any drop height, any thickness, any static loading). By means of this method we are able to define a cushion curve of a given materiel in approximately 2 hours.

This paper investigated the cushion curves for the EFP on standard conditions (according to the standards requirements). But a further research filed can be to investigate the effect of the varied temperature and relative humidity during the testing.

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