POSSIBLE METHOD TO DEFINE CUSHION CHARACTERISTIC ON NEW TYPE OF ENVIRONMENTAL FRIENDLY FOAM

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Abstract: In this paper, we wrote about that packaging device, which can be a critical component in the defense against the logistic stresses. This device is the foam based move damping or cushioning system. The continuous developing of the materials give us the possibility to apply new and possible environmental friendly packaging (EFP) materials. To apply these materials we have to know many parameters for example the cushion characteristic. We investigate a method, already applied in the field of common plastic cushions, but we don’t know yet, how it works with an EFP material. This method can make easier the development process.
1. INTRODUCTION

If we investigate a product – 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 choose the suitable material quality and thickness for the product, is works well in the field of common synthetic polymers, but we don’t know how it works with EFP cushions. However the synthetic polymers fulfil the cushioning function, the environmental aspects stronger and stronger in the designing of product – 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 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 those 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 try to implement a predicting methodology for an environmental friendly and biodegradable cushion material. This progressive analysis based methodology is well works in the synthetic foams.

2. “ENVIRONMENTAL FRIENDLY” CUSHIONS IN THE PACKAGING

If we investigating any statistical figure in the field of packaging, we easily declare that the plastics means a huge part from the packaging generated wastes. From that percentage, the foams means cc 10% as weight, but it is easily countable that it is a huge volume. So these industrial applied plastic foams highly grows the packaging waste volume.

In the initial situation, when a new product – packaging system developed, many times, the engineers gloze over about investigating the possible 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 which 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 solute 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, going to get a solution for the packaging engineers. The new environmental friendly materials possible be able to pass those requirements which defined by environmental and packaging standards. The group 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 figure is well illustrating those materials, which are going to get higher focus in the field of industrial packaging development [2].

![Figure 1: Current and emerging bio-based plastics and their biodegradability](image)

To understand the processes and tendencies of environmental friendly foams, we have to clearly define those terms, which are appears in the field of any kind of degradability. There are many papers, which are well defined the details of these processes, so we don’t write the details of the process [3, 4].

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

![Figure 2. 3 type of foam, applied as a cushion material (source: own photo)](image)

1. Normal PE foam with 35 kg/m³ density, (from only one layer). The solutions if the material became waste are the followings: recycling after sorting or the energetic utilization
2. Multilayered PE foam (35 kg/m$^3$ density) with additive, which can accelerate the degradation process of the material.
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 [5]

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.

3. METHODOLOGY TO PREDICT DYNAMIC CHARACTERISTICS

A mechanical shock or impact occurs, when an 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.

![Figure 3. Registered shock during a drop on a packaged product (source: own measurement)](image)

In cushioned product packaging system, surely the cushion’s aim to decrease and decelerate these critical values as it possible.

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 in these cases, 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 [6].
This method for constructing cushion curves is based on standardized procedure. 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 150 hours of test time. Even more samples and time would be required to fill in the data for other cushion thicknesses and drop heights [6, 7].

4. A NEW METHOD TO CALCULATE THE CUSHION CURVE ON NEW PACKAGING 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. 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.

The dynamic stress can be defined in \( G_s \) (\( G \) times static loading), and the dynamic energy can be defined as \( s \cdot h / t \) (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.

1st step: You have to set the maximum and minimum limits on the energy absorbed. Because of energy = \( s \cdot h / t \), 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.

\textbf{2nd step:} Divide the energy range in step first into about 5-10 approximately evenly spaced points. If the range 5 to 100 kPa 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 100 kPa.

\textbf{3rd 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 \(s\cdot h/t = 20\) are:

<table>
<thead>
<tr>
<th>Static loading (kPa)</th>
<th>Height (mm)</th>
<th>Thickness (mm)</th>
<th>Dynamic energy (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 1. Variables for calculating dynamic energy (source: own measurement)

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 millimetres, 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 apply HBM-Spider 8). These have to be completed for the six drops corresponding to an 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 an energy of 20 kPa.

The mean in this case is 70.1 kPa and the standard deviation is 3.67 kPa, which is 5.2% of the mean.

\textbf{4th 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.
A. Mojzes and P. Borocz

Table 2. The calculated and performed G’s level in dynamic energy of 20 kPa (source: own measurement)

<table>
<thead>
<tr>
<th>Static loading [s [kPa]]</th>
<th>Height [h [mm]]</th>
<th>Thickness [t [mm]]</th>
<th>Captured G’s [g]</th>
<th>Dynamic energy [s·h/t [kPa]]</th>
<th>Stress = G’s [kPa]</th>
<th>Average [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400</td>
<td>20</td>
<td>68.5</td>
<td>20</td>
<td>64.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>30</td>
<td>37.5</td>
<td>20</td>
<td>75</td>
<td>75.5</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>30</td>
<td>26.8</td>
<td>20</td>
<td>80.4</td>
<td>77.3</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>40</td>
<td>17.9</td>
<td>20</td>
<td>71.6</td>
<td>70.1</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>30</td>
<td>13.5</td>
<td>20</td>
<td>67.5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>10</td>
<td>9.8</td>
<td>20</td>
<td>58.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. The calculated acceleration (G) on each static loading for a given material (source: own measurement)

<table>
<thead>
<tr>
<th>Dynamic energy [kPa]</th>
<th>G’s [g]</th>
<th>Variation in percent [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>70.1</td>
<td>5.65%</td>
</tr>
<tr>
<td>40</td>
<td>106.18</td>
<td>1.81%</td>
</tr>
<tr>
<td>60</td>
<td>127.58</td>
<td>4.28%</td>
</tr>
<tr>
<td>80</td>
<td>316.45</td>
<td>7.11%</td>
</tr>
<tr>
<td>100</td>
<td>785.56</td>
<td>6.07%</td>
</tr>
</tbody>
</table>

5th 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:

\[ \text{stress} = a \cdot e^{b(\text{energy})} \]

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 5. [6; 7]

4.1. 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 4. 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 \(R^2\) 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 have been archived by the authors.
5. CONCLUSION

Curve fit 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) and be able to define a cushion curve of a given material in approximately 3 hours. This method is very familiar which is used in 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. The main consequence of the investigation was that, we are able to implement the method for a new environmentally friendly packaging material, which helps us to apply these materials as soon as possible.

REFERENCES