CUSHION DYNAMICS
OF
MOLDED PULP

Prepared by

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Abstract
The paper covers a brief history of molded pulp packaging. How molded pulp packaging is manufactured. How to design the molded pulp cushions for shock and some of the pitfalls that may be encountered in the design of the molded pulp cushions.

Introduction
As a cushioning medium, molded paper fiber (pulp) has been around since the early Egyptians, but grew in popularity and commercial viability in the early 1900’s. With more attention being paid to the environment cushion systems manufactured from sustainable recycled and recyclable materials has brought molded pulp back into favor as a cushioning material.

This paper discusses the manufacturing process of molded pulp cushions, the shock dynamics of these cushions, how these dynamic properties are changed with the design of the cushion shape, the materials used to construct it, and different ways of characterizing these properties.

The manufacturing process for molded pulp cushions
The basic raw material used to construct molded pulp cushions is recycled, corrugated newsprint and other mainstream paper waste. The material is sorted for its end-use purpose and then re-hydrolyzed in a beater/mixer operation. The hydrolyzation or wetting of the pulp fibers is nearly identical in concept to that found at the wet end of a paper machine. A slurry of about 4% pulp and 96% water is then fed into a head box on the forming equipment.

The two main types of molding are pressure and suction molding. Pressure molding is an older process where, “…the pulp mixture is fed into the mold and the product is formed using hot air under pressure. This process is semi-automatic and there for lower output. Additionally, samples made by the pressure-forming process have a thicker and more variable wall thickness. The pressure-process is also less suitable for producing more complicated designs and it has been superseded by suction molding process.” During the suction molding process, a male mold form is injected into the slurry and vacuum is applied to the porous portions of the mold. This vacuum attracts the water and fiber mix to the mold form. After an appropriate dwell, the mold is removed from the slurry box and transferred to a female mold form which shapes the outside portion of the finished part. The parts are then transferred to a dryer (normally a conveyer oven) in order to reduce the moisture content to the appropriate level. This process provides for a smooth side to allow for either printing or a label to be adhered.
Key variables in the process include the percentage of water and pulp in the slurry mix, fiber length, the design of the mold, the dwell time that the mold is in the slurry mix and finally, the drying time, rate, and uniformity of the ovens.

**Pulp cushioning characterization and dynamics**

As a solid material, pulp cushions generally have poor dynamic properties because of relatively high stiffness and lack of compressibility. Pulp becomes a legitimate "cushion" material primarily as a function of its shape and the deformation or crushing of that shape.

Currently accepted cushion test procedures (ASTM D1596, D4168, D3575, etc.) assume that a material can be characterized as a right rectangular prism and functions in a compressive manner. Since pulp cushion dynamics are largely shape-dependent, new or modified procedures are required in order to determine its impact and vibration performance properties.

The procedure established for the testing described herein is a modification of the ASTM D4168 procedure commonly referred to as the *Enclosed Test Block Method*. This procedure requires the use of a "block" (in this case, a 10-inch cube) into which weights can be added in order to change its mass. It also has provisions for mounting a response accelerometer in the approximate geometric center of the block.
Cushion Impact Testing

To construct a cushion curve from pulp material, the cushion should be placed on the enclosed test block which is then placed into a rigid outside container. The assembly should be attached to the platen of a shock test machine and then subjected to a series of shock impacts with a known velocity change. The equivalent drop height can be calculated by using the formula $h = \frac{\Delta V^2}{2g}$. Where “$h$” is the drop height, “$\Delta V$” is velocity change and $g$ is the gravitational constant with units of in/s$^2$. The response deceleration transmitted through the cushions and to the test block will be monitored by the response accelerometer mounted inside.

Following generally accepted cushion test procedures, five impacts should be conducted at each loading level and drop height combination. The loading levels should be recorded in weight per linear inches rather than pounds per sq. in. (PSI), which is the normally accepted presentation. PSI is a relatively meaningless term when dealing with shape deformation because the actual area of contact of the cushion varies as a function of cushion deflection.

Test should be conducted on cushions with normal moisture content (7%) and high moisture content (approximately 13%). Therefore, proper conditioning of the samples is essential. Similarly, the testing should be conducted on any expected combination of recycled content as the amount of recycled content may affect the cushioning properties of the molded pulp material.

A 1994 study of the cushion properties of molded pulp by Danny G. Eaglton and Jorge A. Marcondes published in Packaging Technology and Science Vol. 7 65-72 (1994)$^{iv}$ compares the cushion properties of Expanded Polystyrene (EPS) to Molded Pulp for shock performance characteristics. The study found that, at static loadings between 0.29psi and 0.58 psi, EPS performed as well if not better than Molded Pulp material loaded at equivalent lb./in. At loadings above 0.58 psi, the EPS outperformed the Molded Pulp. The study concluded that Molded Pulp is best used for low drop heights and low static loadings.

Example of Laboratory Data Summary

The table below shows an example of cushion curves for a 36 inch drop height. The three curves represent three different thicknesses of molded pulp material. The x-axis is static stress and the y-axis is deceleration in g’s. The graphs below were derived using the test method described above.

When using this type of graph as a design tool, you should first know the fragility of your product. Once you have determined product fragility, you can use the cushion curve to find the optimally loaded cushion system for impacts. For example, if your product is damaged when it receives a 40 G input, you could either use $t_2$ or $t_3$ from the graphs below as they both have deceleration levels that fall below the 40 G...
level. There are reasons for using either curve. T_3 would have the widest range of possible loadings, from 3 lb./in to 13 lb./in. T_2 has a lower range of loadings from 3.75 lb./in to 6.25 lb./in, but uses less material and would most likely be better for the environment.
Cushion Vibration Testing

In a similar manner, the vibration characteristics of the pulp shapes can be investigated using the same enclosed test block method described earlier. For this test, however, the cushion and block assembly should be subjected to sinusoidal vibration input over the frequency band of approximately 5-200 Hz at an input acceleration level of 0.5 G. Resonant peaks for each loading level will be determined. These peaks can then be combined in an amplification/attenuation plot referred to as transmissibility. Similar tests should be conducted for each variable of moisture content and material. At the time this paper was distributed there was not much research available on the transmissibility of molded pulp cushion systems. More research should be conducted as all products will receive vibration inputs in the shipping and distribution environment. An optimal test procedure has not been developed for Molded Pulp cushion systems. The combination of heavy loads, rigid cushions, and high frequency response make the data difficult to collect and interpret.

Things to Consider For Impact of Molded Pulp Cushions

When evaluating molded pulp as a possible cushion system to protect a product from impact hazards during distribution, there are some things you may want to consider during the design process.

1. Cushion curve results are sensitive to the mechanics of running the test; flatness of the impact surface, condition and uniformity of the test samples, etc.
2. Transmitted deceleration is relatively constant over a fairly wide range of loading, once cushion deflection begins.
3. For most of the pulp shapes, it takes a healthy "push" to initiate deformation or crushing. This characteristic is very shape dependent and should be taken under consideration when designing the molded pulp cushion
4. Dynamic recovery of molded pulp cushions is poor. Curved rib sections have fair to good recovery if the loadings don't bottom (flatten) the cushion. Flange sections have very poor recovery.

Conclusions

Molded pulp has been used as a cushion material since early Egyptian times. With the development of the cushion curves for molded pulp, it is now possible to engineer the design of the material. Molded pulp cushions can be used for a variety of cushioning needs. The use of molded pulp cushions on a vibration sensitive product must be approached with caution and taken on a case by case basis. However, molded pulp cushions are effective in mitigating transmitted shock depending on the fragility of the product. At certain static loadings molded pulp performs as well, if not better than polymer based EPS cushions.
How well the cushion works is dependent on factors such as shape and design of the molded part, cushion thickness built into the design, loading on the cushion, drop height, design expertise of the manufacturer, and uniformity of wall thickness. A well designed molded pulp cushion has distinct advantages over polymer based cushioning material for high volume, rugged products.

Bibliography:


iii Ibid.