Use of Wastepaper for Developing Environment-friendly Shock-absorbing Materials

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ABSTRACT

Environment-friendly shock-absorbing materials were made of wastepaper such as old corrugated containers (OCC) and old newspapers (ONP) with a vacuum forming method. The plate-like cushioning materials made of OCC and ONP respectively by vacuum forming showed superior shock-absorbing properties with lower elastic moduli compared to expanded polystyrene (EPS) and pulp mold. Even though the plate-like materials had many free voids in their fiber structure, their apparent densities (≈0.1 g/cm^3) were a little higher than that of EPS (≈0.03 g/cm^3) and much lower than that of pulp mold (≈0.3 g/cm^3). However, the elastic moduli of the cushioning materials made of wastepaper were much lower than that of EPS or pulp mold. This finding implies that the cushioning materials made of OCC fibers containing more lignin than ONP show better shock-absorbing properties than ONP. Moreover, the cushioning materials made of OCC and ONP respectively showed greater porosity than pulp mold. The addition of cationic starch to the cushioning materials contributed to an increase in the elastic modulus to the same level as that of EPS. Furthermore, the deterioration in fiber quality by repeated use of wastepaper played a great role in improving shock-absorbing ability.

INTRODUCTION

In the early 1900s, the Dow Chemical Company invented a process for extruding polystyrene (styrofoam) to achieve a closed-cell foam that endures external impact. Expanded polystyrene has been widely used in various ways worldwide but the waste from the material has come to be regarded as non-degradable material in the soil (*Letcher & Sheil 1984; Alanko, K 199;*). Many countries have introduced laws to give manufacturers extended responsibility for once-used polystyrene. These laws mean that non-degradable materials used for shock-absorbing packing during goods distribution will be entirely prohibited in the near future. From the environmental point of view, new alternatives able to replace expanded polystyrene (EPS) must be developed in the face of the tightened demands for earth-friendly packaging by the governments.

A large amount of wastepaper is generated every day, but around 60 per cent of the paper is recycled and the rest is abandoned. The available recycling number of wastepaper is no more than 5 times due to hornification (*Scallan et al., 1991*). Therefore, it is imperative to find a fresh use for much-deteriorated wastepaper. Currently, the most frequently used method for reusing deteriorated wastepaper is to make a pulp mold cushion with shock-absorbing ability, such as an egg case. Pulp molds are molded from suspended wastepaper with a filter press under high vacuum. Thus, their z-directional structure is highly densified, which is different from EPS, and the mold materials themselves do not have any capacity to protect packed goods (*Patel et al., 2004*). In order to allow the pulp molds to absorb external impacts, their shapes must be molded to the shapes of packed goods with an empty space for packing cushion. In this aspect, the cushioning effect of the pulp molds is quite different from that of EPS, which contains inherent shock-absorbing properties.

For replacement of EPS, new cushioning materials with 100 per cent biodegradable nature must be developed. Wastepaper with deteriorated fiber quality has been chosen as the raw material to make shock-absorbing materials leading to minimal impact to the environment. The new cushioning materials made of wastepaper could be a direct replacement for and a perfect alternative to EPS packaging in this new era of environmental awareness.

For making a pulp suspension, the vacuum forming method without wet press was applied, which left lots of voids in the inner structure of the cushioning materials. In this paper, through the comparison of the physical properties of the shock-absorbing materials with those of EPS, it will be confirmed that the biodegradable cushioning materials have better properties than EPS.

MATERIALS AND METHODS

Pulping

The wastepaper used for the cushioning material was from old corrugated boxes and old newspapers collected in a local Korean city. The wastepaper was dry-disintegrated by Wonder Blender (WB-08, Sanplatec Corp., Japan), and then suspended with cationic starch (Samyang Genex Co., Korea) at 3 per cent consistency.

In order to explore the effect of recycling the cushioning materials, the once-used materials were dry-disintegrated and then vacuum-formed, as above.

Vacuum forming

The suspension of wastepaper was put into the forming box of the vacuum former manufactured by the pulp and paper technology laboratory of Gyeongsang National University, and then drained under a vacuum of 760 mmHg for 10-60 seconds. The formed fibers were dried at about 150±3 °C and conditioned up to 50±2% RH and 23±1 °C.

Measurement of physical properties of the cushioning materials

Apparent densities of the cushioning materials were calculated from their volumes and weights. The compression strength of the cushioning materials was measured with a Texture Analyzer (TA-XT2i, Stable Micro Systems Ltd., UK) based on ASAE 368.3. The compression strength was converted to elastic modulus. The void ratio of the materials was measured using microtomed sections of the resin-embedded materials using an AxioVision image analyzer (ver. 4, Zeiss, Germany) connected to an Olympus microscope (Japan).

RESULTS AND DISCUSSION

The apparent density of the cushioning materials made using different suctioning times is shown in Fig. 1. Increased suction time led to a slight increase in the apparent densities of the cushioning materials of OCC and ONP respectively. The extent of the increase was higher in OCC than in ONP. Since OCC fibers are mostly composed of lignin-containing unbleached kraft pulps, their bonding ability is lower than ONP containing old bleached magazine paper and old newspaper (*Howard et al., 1992; Letcher & Sheil 1984*). The low bonding potentials contributed to less compaction during material forming and thus created less increase in density. A low density means that the inner structure of the material is so porous that it is able to play a significant role in absorbing external impacts.

Irrespective of suction time, the cushioning materials made of OCC and ONP showed much lower densities than pulp mold and higher densities than EPS. This is caused by differences in the manufacturing process, such as molding by wet press and expansion of polymers. Despite the higher densities of OCC and ONP cushions than EPS, it appears that they have great capacity to absorb external impacts during the distribution of packed goods.

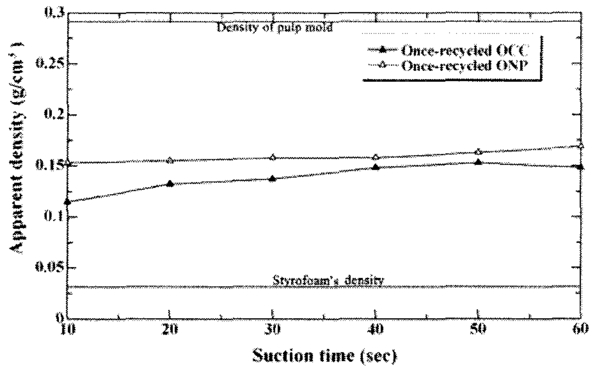


Figure 1. Effect of suction time on apparent densities of cushioning materials.

The suction time during forming greatly affected the elastic moduli of the cushioning materials made of the two types of wastepaper respectively (refer to Fig. 2). In particular, the materials from OCC were far more sensitive to this change than those from ONP. It seemed that OCC with low interfiber bonds was physically readily compacted by increased vacuum, which was different from ONP with its relatively high interfiber bonds. In contrast to apparent density, it is interesting to note that the elastic moduli of the two materials were much lower than the elastic modulus of EPS. A low elastic modulus means that the textures of the cushioning materials are easily deformed by external forces greater than the critical load. The two materials can endure any external impact below the critical load. It is also important to note that the elastic modulus of the cushioning materials can be easily supplemented by bonding additives like cationic starch. However, the lower elastic moduli of the materials from OCC and ONP than that of EPS will make a big contribution to better shock absorption than EPS. For reference, the elastic modulus of pulp mold was about 1770 kPa, much greater than that of the wastepaper cushions and EPS.

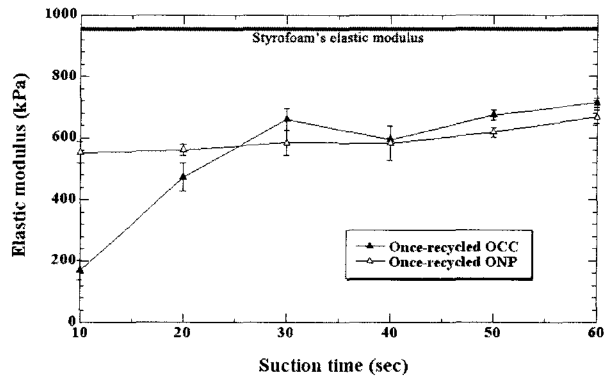


Figure 2. Effect of suction time on elastic moduli of cushioning materials.

For improving the elastic modulus of the OCC cushion, cationic starch was added to the wastepaper suspension (*Davidson et al., 1984; Yu et al., 1999; Eriksson 1995*). As shown in Fig. 3, different addition levels of cationic starch did not lead to any great change in density irrespective of recycling frequency. Thus, cationic starch only played a minor role in improving interfiber bonds without contributing to the densification of the cushioning materials.

The contribution of starch to improved interfiber bonds could be confirmed by the measurement of the elastic moduli of the materials, as shown in Fig. 4. The material from the once-recycled wastepaper showed the greatest increase in elastic modulus with the addition of cationic starch. Further addition of cationic starch increased the elastic modulus less than before. It was clearly shown that the low elastic modulus of the cushioning material could be easily complemented by bonding additives.

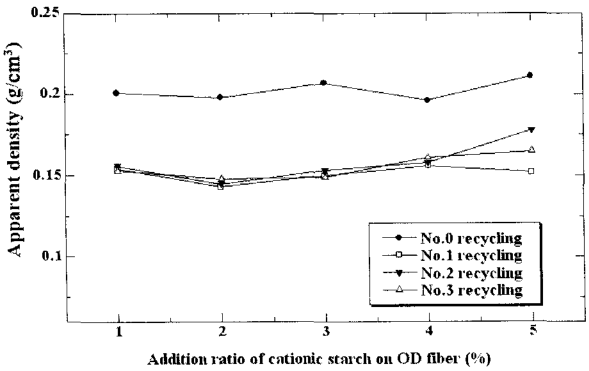


Figure 3. Effect of cationic starch addition on apparent density of a cushioning material.

Fig. 3 and Fig. 4 also show the effect of recycling numbers on the density and elastic modulus of the shock-absorbing materials. It is well known that repeated use of wastepaper leads to deterioration of fiber quality due to hornification. Secondary fibers that have repeatedly undergone hornification have very poor bonding ability with reduced flexibility. Therefore, the repeated use of wastepaper results in a decrease in both apparent density and elastic modulus. If the shock-absorbing materials require low elastic moduli, wastepaper composed of much-deteriorated fibers, i.e., frequently reused paper, may be used (*Stenius et al., 2000*).

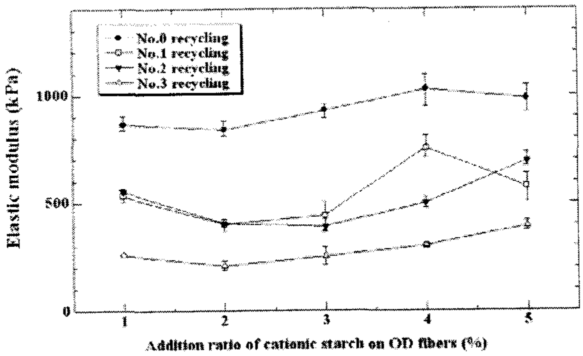
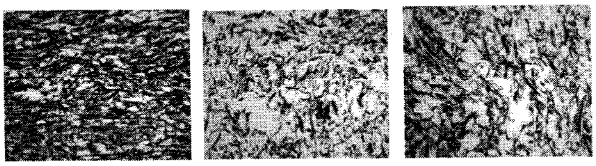


Figure 4. Effect of cationic starch addition on elastic moduli of a cushioning material.

Fig. 5 shows the cross-sectional views of pulp mold and cushioning materials made from OCC and ONP. It can easily be observed that pulp mold had a highly densified structure in the z-direction, which was different from OCC and ONP. The porosity of each measured by image analysis was 26% for pulp mold, 74% for OCC, and 59% for ONP. As indicated in the above results on apparent density and elastic modulus, it was readily ascertained that the material from OCC with the greatest porosity would show the best shock-absorbing ability.



(a) pulp mold (b) OCC (c) ONP

Figure 5. Cross-sectional views of pulp cushions.

Conclusions

The biodegradable cushioning materials were made from wastepaper such as OCC and ONP with a vacuum forming method. The plate-like cushioning materials made of OCC and ONP respectively by vacuum forming showed superior shock-absorbing properties with lower elastic moduli compared to EPS and pulp mold. Even though the plate-like materials had many free voids in their fiber structure, their apparent densities were higher than EPS. However, since the solid content of the materials made with a dual-vacuum forming method decreased, their density could be decreased without sacrificing their shock-absorbing ability. The materials made of OCC fibers containing more lignin than ONP showed better shock-absorbing properties than did ONP. Moreover, the shock-absorbing materials made of OCC and ONP respectively showed much better shock-absorbing properties with greater porosity than pulp mold. The addition of cationic starch to the cushioning materials contributed to an increase in elastic modulus to the same level as that of EPS. Furthermore, the deterioration in fiber quality by repeated use of wastepaper played a great role in improving shock-absorbing ability.

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