Use of Waste Woods for Developing Environment-friendly Shock-absorbing Materials

CHUL-HWAN KIM†, **DAE-BIN SONG**†1), **YOUNG-MIN LEE**‡, **JAE-OK KIM**‡, **GYEONG-YUN KIM**‡
TAE-GI SHIN‡ **and CHONG-YAWL PARK***

†Associate Professor, ‡Graduate Students, *Professor
Division of Env. Forest Sci., IALS, Gyeongsang National Univ., Jinju, 660-701, Korea
1)Dept. of Bio-Industrial Machinery Engineering, IALS, Gyeongsang National Univ., Jinju, 660-701, Korea
Corresponding Author's E-mail: jameskim@gnu.ac.kr

ABSTRACT

Environment-friendly shock-absorbing materials were made using a vacuum forming method from waste wood collected from local mountains in Korea. The waste wood was pulped by thermomechanical pulping. The TMP cushions showed superior shock-absorbing properties with lower elastic moduli compared to EPS and pulp mold. Even though the TMP cushions made using different suction times had many free voids in their inner fiber structure, their apparent densities were a little higher than EPS and much lower than pulp mold. The addition of cationic starch improved the elastic modulus of the TMP cushions without increasing the apparent density, which was different from surface sizing with starch. The porosity of the TMP cushions was a little greater than EPS and much less than pulp mold. Finally, the TMP cushions have great potential to endure external impacts occurring during goods distribution.

INTRODUCTION

Polystyrene (EPS) is a strong plastic created from ethylene and benzene that can be injected, extruded or blow molded, making it a very useful and versatile manufacturing material. EPS has been widely used in various ways worldwide, but the waste after use has come to be regarded as a nuisance due to its non-degradable characteristics: furthermore, CFCs are used in its production. Consequently, many countries have introduced laws to prohibit the extended use of EPS. These laws mean that non-degradable materials used as packing cushions 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 (*Patel et al., 2004; Riggle 1998*).

For provision against the foreseen prohibition of EPS, biodegradable shock-absorbing materials must be developed. The best alternative raw materials to EPS are plant fibers from woods, which are easily exposed to microbes in a soil. The fibers produced from mature are too expensive to be used as a raw material for making cushioning materials. Therefore, waste wood, which has little economic efficiency in Korea, can be regarded as an optimum raw material.

It has been reported that waste wood (logging residues) generated in Korea constituted about 40 per cent of the total amount of wood used in 2000. It is interesting to note that waste wood in Korea has been generated at a ratio of about 23% every year since 1999 (*The Research Forest, Research Materials 2001*). However, since the practical use of waste wood has been dropping year after year, fresh applications should be developed for it.

In this study, a cushioning material was developed by a vacuum forming of virgin pulp fibers made of waste wood. Cushioning materials from waste wood would contribute to the increase of the economic value of waste wood as well as being a substitute for EPS. The new cushioning materials made of waste wood would be a direct replacement for and a perfect alternative to EPS packaging in this new era of environmental awareness.

For making a pulp suspension from waste wood, the vacuum forming method without wet press was applied, which left lots of voids in the inner structure of the cushioning materials. The physical properties of the cushioning materials were compared with those of EPS, which led to the confirmation that the biodegradable cushioning materials had better properties than EPS.

MATERIALS AND METHODS

Pulping

Waste wood less than 18 mm in diameter was collected in the Research Forest in Gyeongsang National University in Korea. The waste wood was chipped by an experimental disk chipper to a size of about 25×25×10 mm. The chips were pre-steamed under 110-120±5°C and 50 kPa for around 3 minutes, and then refined by a single disc refiner (Daeil Machinery Co., Korea). The refined fibers were suspended with cationic starch (Samyang Genex Co., Korea) at 3 per cent consistency.

Vacuum forming

The suspension of TMP fibers 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.

Surface sizing

In order to prevent fiber dust from being detached from the surface of the TMP cushions, surface sizing was performed with 1% starch.

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 (porosity) 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 materials. The apparent density of the TMP cushions was much lower than that of pulp molds and was a little higher than that of EPS. Since pulp molds are extremely compacted by wet press and high vacuum, their structures are highly densified. On the other hand, the TMP cushions formed without wet press could maintain high bulk. In addition, TMP fibers containing a large amount of lignin have extremely low bonding potentials leading to a low density of a resultant cushions. TMP fibers with high lignin contents were not seriously affected by suction time (*Adamson et al., 1997*). A low density means that the inner structure of the TMP cushions is so porous that it is able to play a significant role in absorbing external impacts (refer to Fig. 2). The TMP cushions sectioned at 20 μm had a wide area of empty voids, which was different from pulp mold sections. The large area of the voids observed in both the TMP cushions and EPS resulted in good cushioning ability.

Irrespective of suction time, the cushioning materials made of TMP fibers showed higher densities than EPS. This is caused by difference in the manufacturing process, such as the expansion of polymers. However, the difference in densities between the TMP cushions and EPS was not as big as expected. Despite the higher density of the TMP cushions than EPS, it appears that they have great capacity to absorb external impacts during the distribution of packed goods.

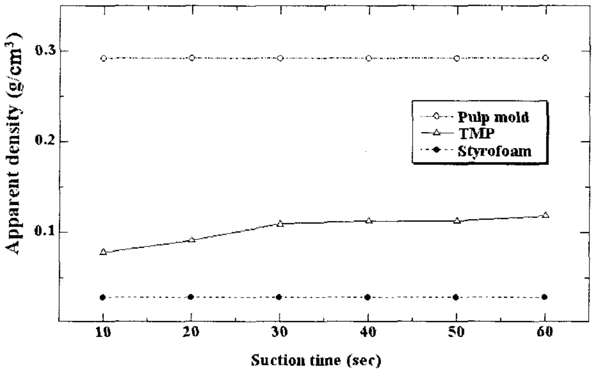
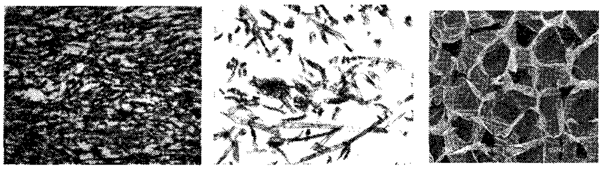


Figure 1. Effect of suction time on apparent densities of cushioning materials.



(a) pulp mold (b) TMP cushion (c) EPS

Figure 2. Cross-sectional views of various packing cushions.

Apart from the density, as shown in Fig. 1, the suction time during forming also greatly affected the elastic moduli of the cushioning materials made of the waste wood. As shown in Fig. 3, the TMP cushions were far more sensitive to change due to alterations in suction time during forming. The elongated suction time produced interfiber bonding of the TMP fibers without a major consolidation of a fiber matrix. That is, the increased suction time only contributed to the improvement of the bonding force at contact points between neighboring fibers. Even though long suction times increased the elastic moduli of the TMP cushions, their elastic moduli were 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. On the other hand, it also means that the material can endure any external impact below the critical load.

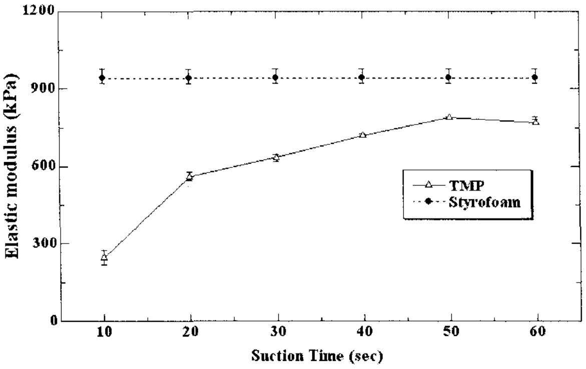


Figure 3. Effect of suction time on elastic moduli of cushioning materials.

It is also important to note that the elastic modulus of the cushioning materials can be easily supplemented by bonding additives like cationic starch. Table 1 shows that the addition of cationic starch increased the elastic moduli of the TMP cushions very sharply despite the short 10-second suction time. However, the apparent density did not show a sensitive response to different addition levels of cationic starch. It seems that cationic starch played a major role only in improving interfiber bonding without influencing the densification of the TMP cushions (*Neimo 1999*). Finally, it became evident that the low elastic modulus of the TMP cushions does not much matter because both the optimum suction time and the use of bonding additives can help to increase the elastic modulus of TMP cushions up to the level of that of EPS.

On the other hand, the low elastic modulus of the TMP cushions would make a major contribution to their better shock absorption than EPS. The elastic modulus of pulp mold was about 1770 kPa, much greater than that of the TMP cushions and EPS. Thus, pulp mold itself with a plate-like shape does not have any ability to absorb external forces, which is different from the TMP cushions and EPS.

Table 1. Effect of cationic starch addition on apparent density of a cushioning material: the suction time was fixed to 10 seconds

	Cationic starch (%)[2]		
	10	20	30
Elastic modulus (kPa)	245.50	439.20	546.52
S.D.[1]	22.34	14.29	17.69
Apparent density(g/cm^3)	0.078	0.082	0.086
S.D.	0.005	0.005	0.006

[1] S.D.: standard deviation.

[2] Based on OD pulp weight

Fig. 4 shows the effect of surface sizing on the apparent density of TMP cushions. Surface sizing was undertaken with a TMP cushion formed under 10 seconds of vacuum. When additional coating was applied to the surface, a greater increase in apparent density was gained. It is believed that the starch molecules play a positive role in improving the interfiber bonding of TMP fibers on the surface (*Adams 1983; Lee et al., 2002*). Fig. 6 shows the surface microphotography before and after surface sizing of a TMP cushion. The surface texture after surface sizing was more densely covered by starch molecules than before. Finally, it was clearly observed that surface sizing including internal addition of starch increased the apparent density of TMP cushions.

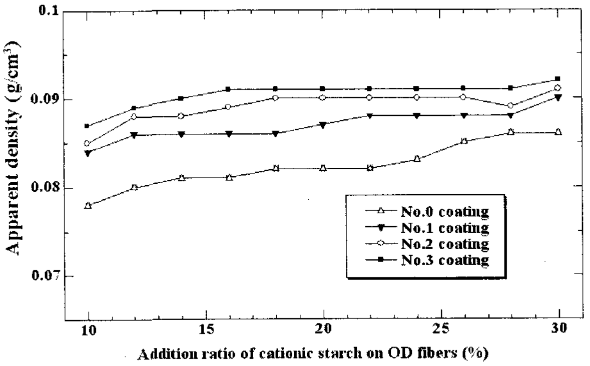
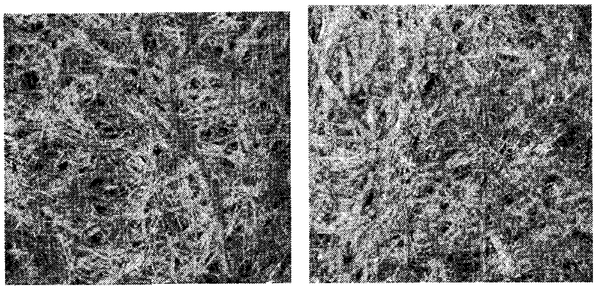


Figure 4. Effect of surface sizing and starch addition on apparent density of TMP cushions.



(a) Before sizing (b) After sizing

Figure 5. Microphotography of the surface of a TMP cushion before and after surface sizing.

Fig. 6 shows the effect of surface sizing with starch on the elastic modulus of TMP cushions. Increased addition of cationic starch led to an increase in elastic modulus, but different surface sizing frequencies did not much affect the increase in elastic modulus. Finally, it was found that surface sizing with starch merely filled up the surface voids of a TMP cushion, thus raising its density, but the main factor affecting its elastic modulus was merely the internal addition of cationic starch.

Therefore, the combined treatment of surface sizing and the internal addition of starch could contribute to the improvement of the elastic modulus without greatly affecting the density.

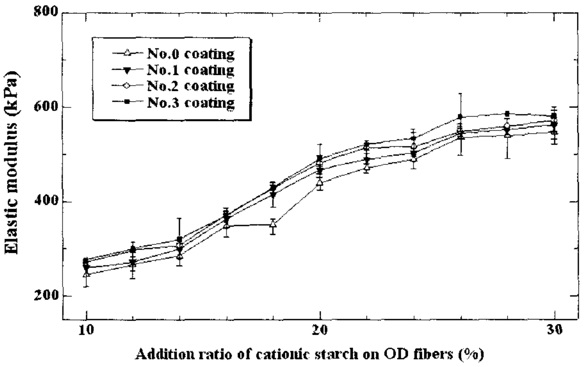


Figure 6. Effect of surface sizing and internal addition of starch on elastic moduli of TMP cushions.

The porosity of TMP cushions with cationic starch formed under 10 seconds of vacuum was measured using 20 μm thick microtomed sections. Their porosity was about 72%, which was less than that of EPS (98%) and much greater than that of pulp mold (26%). Many voids were observed, as seen in the z-directional view in Fig. 2. This finding suggests that their considerable porosity would endow the TMP cushions with a great ability to endure external impacts occurring during goods distribution.

Table 2. Porosity of TMP cushions.

		Cationic starch (%)[2]			
		0	10	20	30
TMP cushion	Porosity (%)		71.54	73.20	73.16
	S.D.[1]		2.13	3.40	2.15
Pulp mold	Porosity (%)	26.36	N/A		
	S.D.	5.02			

[1] S.D.: standard deviation.

[2] Based on OD pulp weight.

CONCLUSIONS

Biodegradable cushioning materials were made using a vacuum forming method from TMP fibers pulped from waste wood (logging residues). The TMP cushions showed superior shock-absorbing properties with lower elastic moduli compared to EPS and pulp mold. Even though the shock-absorbing materials made using different suction times had many free voids in their inner fiber structure, their apparent densities were a little higher than EPS and much lower than pulp mold. The addition of cationic starch could improve the elastic modulus of the TMP cushions without increasing their apparent density, which was different from surface sizing with starch (*Booth 1993; Hoyland et al., 1977; Gess 1981*). The porosity of the TMP cushions was a little greater than EPS and much less than pulp mold.

REFERENCE

1) Patel, M., Green Plastic Jr. 3(4): 14 (2004).
2) Riggle, D., BioCycle, March: 64-70 (1998).
3) The Research Forest. Waste-wood collected system improvement & recycled promotion plan. Research materials (2001).
4) Adamson, A., and Gast, A.P., Physical Chemistry of Surfaces, 6th ed., John Wiley & Sons, New York (1997).
5) Neimo, L., Papermaking Science and Technology Vol. 4., Papermaking Chemistry, PI and TAPPI Press, pp269-288 (1999).
6) Adams, A. A., Effect of size press treatment on coating holdout, Tappi J., 66(5) : 87~91(1983).
7) Lee, H.L., Shin, J.Y., Koh, C.H., Ryu, H., Lee, D.J., and Sohn, C., Surface sizing with cationic starch: its effect on paper quality and the papermaking process, TATTI Journal, 1(1):34~40 (2002). p.87 January (2002).
8) Booth, G.L., in The Coating Processes, Chap. 3 Sec. IV., Ed. Walter, J.C. TAPPI PRESS, Atlanta (1993)
9) Hoyland, R., Howarth, P., Whitaker, C., Pycraft, C., Paper Tech. Ind. 18(8): 246 (1977).
10) Gess, J.M., Tappi 64(1):35 (1981).

ACKNOWLEDGEMENT

This research was carried out with the financial support of the Agricultural R&D Promotion Center of Korea in 2004.