Degradation of New Cellulose-Based Complex Material

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ABSTRACT: The degradation of a kind of cellulose-based complex material was investigated by the soil bury and exposure methods. The results showed that the average molecular weight of the sample decreased 66.7% and the copper number increased from 1.32 to 7.58 after 9 weeks as measured by the soil bury method. Meanwhile the average molecular weight decreased 38.7% and the copper number increased from 1.32 to 5.00 after 14 weeks of exposure under the sun. © 2001 John Wiley & Sons, Inc. J Appl Polym Sci 81: 809–812, 2001

Key words: degradation; cellulose; complex material

INTRODUCTION

Foamed polystyrene is largely used as food containers and drinking sets. Nowadays the food boxes and drinking cups are discarded everywhere. They badly pollute the rivers, lakes, and land. This is the so-called white pollution. To solve this problem researchers have examined various materials that can be biodegraded to substitute for the foamed polystyrene. The natural macromolecule is thought to be the best selection. From this point of view, we used bagasse as the main material with some assistant additives to make various food containers or drinking sets for single use because a large amount of bagasse is burned every year. Generally, bagasse can be completely degraded by microorganisms in the natural environment, but as mentioned above, some additives must be added into the bagasse for water resistance and oil resistance of the container. We sought to find out how much of an influence these additives have on the degradation rate of the main material. That was a question we wanted to answer in this study. There were some articles published on the study of the degradation of polymers by the method of soil bury and exposure. However, using the bagasse with a few additives for water resistance and oil resistance as the material for food containers was not found. So we wanted to study their degradation capacity by the approach of soil bury and exposure under natural environmental conditions. The degradation rate was expressed as the weight loss, average molecular weight decrease, and copper number increase.

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EXPERIMENTAL

Samples

Ground bagasse was blended quantitatively with some additives for water resistance and oil resistance. Then it was fed into special molding equipment to produce food containers. The inside and outside of the food boxes were coated with a white coating made from a natural macromolecular substance. The food boxes were cut into pieces of a certain size for the degradation tests.

Table I WLR of Samples with Different Degradation Times by Soil Burying

Time (days)	28	35	42	49	56	63
WLR (%)	18.3	26.8	34.1	41.7	47.8	52.5

Table II WLR of Samples with Different Degradation Times by Exposure

Time (days)	28	42	56	70	84	98
WLR (%)	11.9	14.4	17.2	22.8	28.2	32.7

Degradation Tests

Soil Bury Method

The soil bury method[1–4] was selected comprehensively for testing the degradation rate of polymers because the degradation condition was very close to the natural environment. We weighed the sample, selected a piece of land with a certain microorganism, and buried the samples. Then we unearthed the sample every 2 weeks and carefully cleaned the soil on the sample surface. Finally, we measured the weight loss rate (WLR), molecular weight (MW), and the copper number (CN).

Exposure

The samples prepared by the method above were nipped and hanged on a shelf facing the sun outside the building. Four weeks later we took the first sample for testing the same items as above. After that we performed the same procedure every 2 weeks.

Analysis

The weight loss was calculated as follows:

$$S = (W_0 - W_t)/W_0$$

Here W_0 is the sample weight before degradation, and W_t is the sample weight after degradation for a prescriptive time.

The MW was calculated by the GB 1548-79 method. The CN was measured according to GB 5400-85.

RESULTS AND DISCUSSION

WLR Measurements

The WLR of the samples is shown in Tables I and II. It is very clear that the WLR of the sample by soil bury was higher than by exposure at the same degradation time. That was easy to understand because the microorganism was relatively active that attacked the molecular chain of the cellulose and lignin under suitable temperature and humidity conditions to make the molecular chain break down. Also, in the case of exposure the WLR was due to the sunlight affect on the glucoside bond of the cellulose that broke the molecular chain and some times there was no sunlight. We also saw an obvious fact from the data in Tables I and II that this kind of material was easily degraded by soil bury or by exposure even if the additive was introduced.

MW Decrease

Generally, the MW decrease was related to the weight loss as most macromolecules, because the weight loss of the macromolecule meant that some segment of the molecular chain was becoming a small molecule that could be dissolved in water. When the weight of the macromolecule was lost under the action of the microorganism or sunlight their MW was decreased. Figure 1 shows a decreasing trend of the MW. Curves 1 and 2 represent the soil bury method and exposure method, respectively. As we can see from the slope of Figure 1, at the beginning step the MW decreased slowly; after that the slope of the curves became steep. Probably it needed a process for the enzyme to grow and the energy storage of sunlight. A comparison of curve 1 with curve 2 showed that the slope of curve 1 was steeper than curve 2; this demonstrated that the effect of the microorganism to rupture the cellulose chain was

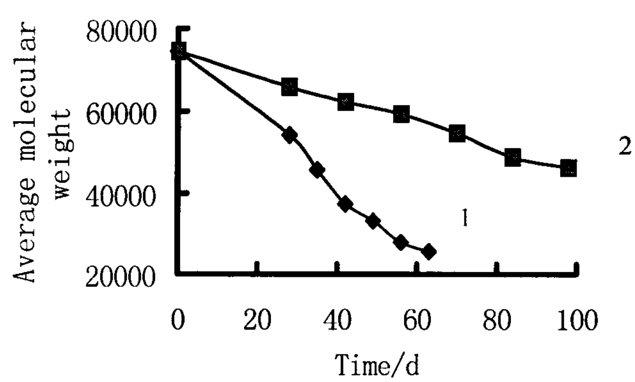

Figure 1 The decrease of the average molecular weight with time as measured by soil burying (curve 1) or by exposure (curve 2).

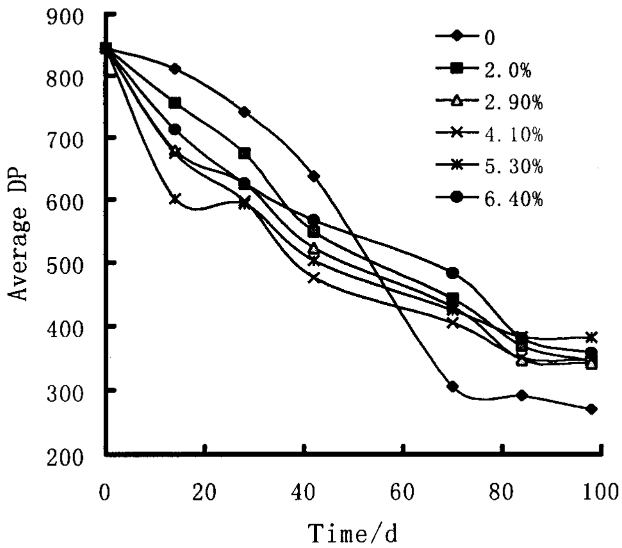

Figure 2 The effect of additives for anti-water and anti-oil on DP.

bigger than sunlight. Of course, the results still depended on the concrete condition of burial or exposure, for example, the soil condition or weather situation.

Figure 2 shows that the effect of additives for anti-water and anti-oil on the degree of polymerization (DP) decreased during burying for degradation. Generally, an additive for anti-water and anti-oil could effect the degradation of the basic material for making food box, but there was some surprise in the data of Figure 2.

The DP of those samples with additive decreased faster than those without additive at the beginning step of degradation. However, the effect of the additive on the degradation of the material still showed to some extent after burial for 14 weeks. We cannot explain this phenomena yet, but it indicated that the additive we chose possessed quite good properties for degradation by microorganisms.

CN Increase

It came to light that the cellulose consisted of β(1-4)-D-glucose. When the molecule chain was ruptured, in most cases the position of rupture was located between C-1 and C-4. So there were two end groups in the glucose: one was the free hydroxyl group and the other was the half-aldehyde group (see Fig. 3). We knew that the half-aldehyde group possessed reductive properties, so we could use the CN to express the amount of ending groups (i.e., the extent of the molecular

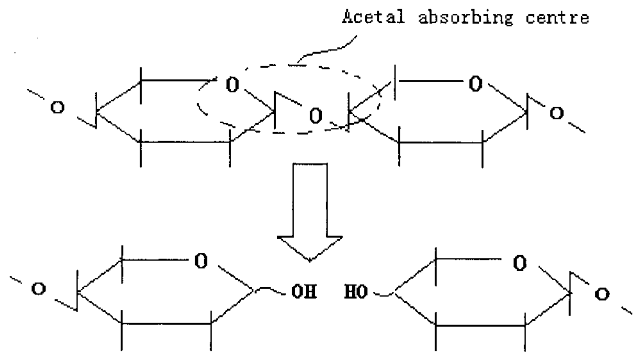

Figure 3 The mechanism of light degradation of cellulose.

chain rupture). Not only a biodegradation reaction but also hydrolytic and oxidative reactions happened during burying.[5,6] These reactions would make the CN of the sample increase.

The CN increased with extending the degradation time, which is very clear in Figure 4. The CN increased slowly for the first 30 days, whether in the case of soil bury or exposure. But there were some differences between the soil bury and the exposure. The slope of curve 1 (Fig. 4) became smooth after 60-day degradation, but the slope of curve 2 did not show a trend of smoothness even after the degradation time was prolonged to 100 days. That meant that the β(1-4)-D-glucoside bond was sensitive to the UV radiation of sunlight. Moreover, the microorganism cut off the β(1-4)-D-glucoside bond and opened the ring of glucose at the same time. Maybe the microorganism preferred to attack the degraded product of low MW, especially for glucose. Thus, the soil bury indicated a bigger weight loss and slower CN increase

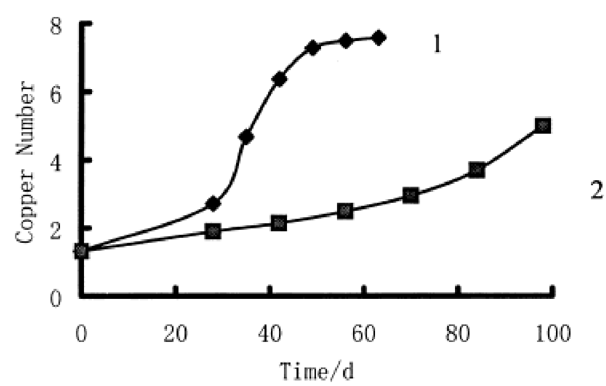

Figure 4 The increase of the copper number with time as measured by soil burying (curve 1) or by exposure (curve 2).

after a certain time of degradation, for example, 60 days.

CONCLUSION

The complex material made from bagasse as the main raw material with some additives possessed a good degradable capacity. After 9-week degradation its WLR was 52.5%, its MW decreased 65.7%, and its CN increased from 1.32 to 7.58 for the soil bury method; with the exposure method they were 32.7 and 38.9% and 1.32–5.00, respectively.

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