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Biodegradation of nonlignocellulosic substances II: physical and chemical properties of sawdust before and after use as artificial soil

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Abstract The physical properties of sawdust including porosity, water retention, and water drainage were analyzed to prove its suitability for use as an artificial soil in the automatic decomposer-extinguisher (GADE) machine. The physical and chemical properties of residual sawdust from the GADE machine were also analyzed, the mechanical abrasion of sawdust in the GADE machine was tested, and the morphology of this residue was observed through a scanning electron microscope to investigate changes of these properties in the medium of decomposing garbage. Sawdust, which showed a lower specific gravity and larger porosity than soil, is considered capable of supplying air to bacteria. It was found that sawdust became worn from the operation of the machine. The spaces of residual sawdust were still observed, but water drainage decreased. The portion of hollocellulose in residual sawdust decreased, although the extractives in it increased. Results indicated that the capacity of sawdust to function as an artificial soil in the GADE machine was decreased owing not only to the destruction of sawdust grain but also to the adherence of products from decomposition, such that sawdust needed to be replaced every few months.

Key words Garbage · Sawdust · Porosity · Water retention · Water drainage

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Introduction

A previous paper reported the food-waste decomposition capacity of the garbage automatic decomposer-extinguisher (GADE) machine.[1,2] This machine decomposes food-related organic waste primarily into carbon dioxide and water by means of bacterial biodegradation in the soil. Sawdust plays a key role as an artificial soil-like matrix used in the GADE machine.[3,4] Properties required of the matrix of this machine are the following: large space-per-unit volume to create aerobic conditions for bacteria; low specific gravity to curtail the energy of mixing; suitable water retention to supply moisture for bacteria; resistance to bacterial degradation; and low material cost.

The grains rub against each other during the mixing process, which gradually causes the sawdust to become worn. Residuals from the degrading garbage attach to the surface of the sawdust grains, resulting in a decline of the properties described above. Features of residual sawdust may need to be investigated to determine when or how often to substitute new sawdust and recycle the used sawdust. In this study the physical and chemical properties of raw sawdust and residual sawdust from the GADE machine were characterized to investigate the ability of this medium to act as an artificial soil matrix in the machine.

Materials and methods

Experimental materials

Sawdust originating from mixed wood species in North America was examined before use (raw) and after use (residual) in the GADE machine (Mitsui Home Co., Tokyo, Japan). It was analyzed for changes in its physical and chemical properties. This machine is designed for a family of three to five people, for a small-sized home, and for decomposing a total of about 60 kg of garbage using 4 kg of sawdust (25 l) during 4 months.[2]

Sawdusts from todomatsu (*Abies sachaliensis* Masters), karamatsu [*Larix kaempferi* (Lamb.) Carriére], and ezomatsu (*Picea jezonensis* Carr) from Hokkaido were used separately as raw materials. In addition, sugi (*Cryptomeria japonica* D. Don), hinoki (*Chamaecyparis obtusa* Sieb Zucc.), and hiba (*Thujopsis dolabrate* var. *hondae* Makino) from Japan proper were prepared for the wear test. These specimens were conditioned to have a moisture content of 10%–11%, and the apparent density was measured separately.

Measurement of porosity

A measured amount of sawdust (100 ml) was put in a cylinder, and water was poured gradually into it until the water level reached the surface level of the sawdust, as shown in Fig. 1. This water volume, V_a, is equivalent to the space or spaces within the sawdust (interspace) and to the spaces between sawdust particles (intraspace); porosity (ε) is the ratio of the air-dried volume of sawdust, V_0 (100 ml), to the volume of water, V_a, shown in the following formula:

$$\varepsilon = \frac{V_a}{V_0}$$

Measurement of water retention

A 100-ml glass column (inside diameter 30 mm) equipped with a tap and a screen of 80 mesh was filled with a sawdust sample as shown in Fig. 2. Water equivalent to the volume of the interspace and intraspace was poured into the column. The tap was opened, and the water was allowed to drain for 10 min. Water retention (WR) was computed as follows:

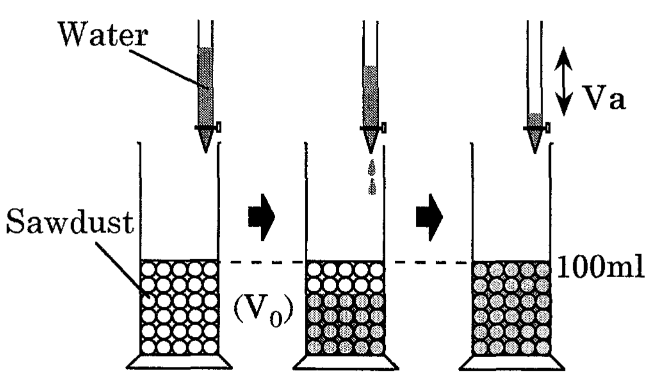

Fig. 1. Measurement of porosity. V_0, volume of sawdust (100 ml); V_a, volume of interspace and intraspace

$$WR = \frac{V_a - V_b}{V_0}$$

where V_b is the volume of drained water, V_a is the volume of interspace and intraspace, and V_0 is the volume of the sawdust.

Measurement of water drainage

A glass column (inside diameter 30 mm) was filled with 100 ml of sawdust and a sufficient amount of water. Water was then drained for 20 min, and the water flow was measured at 30-s intervals as shown in Fig. 3. The drained volume was graphed against time, and water drainage (WD) was computed as the slope of the line.

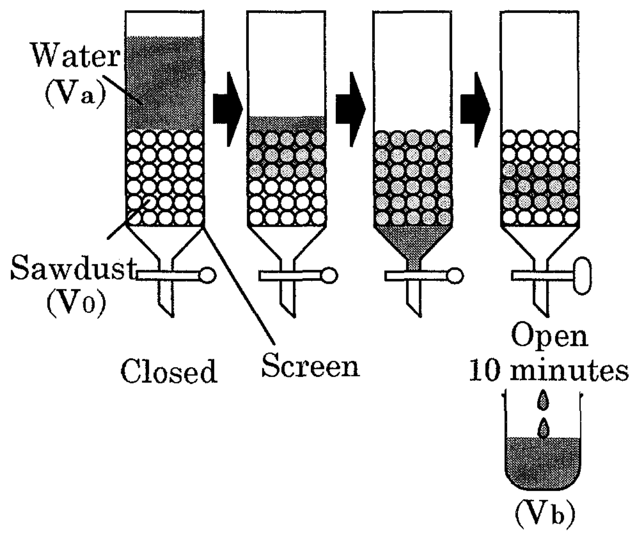

Fig. 2. Measurement of water retention

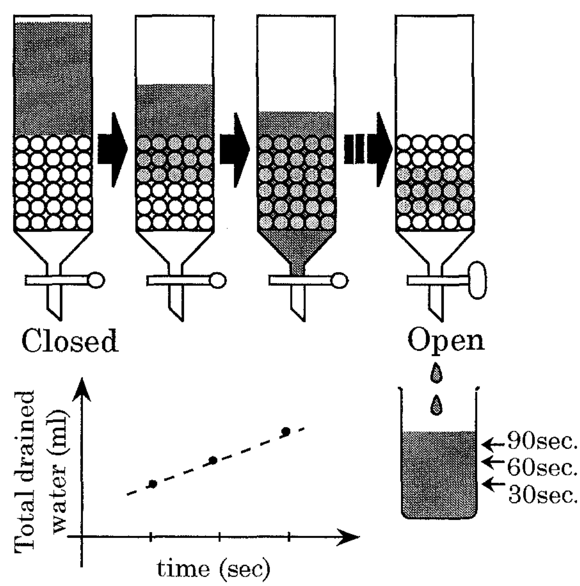

Fig. 3. Measurement of water drainage

Wear test for sawdust

The effects of the working GADE machine on sawdust of various grain sizes was investigated. Sawdust (25 l) from Mitsui Home Co. (a mixture of soft wood from North America), adjusted to a moisture content of 60% (wet basis), was put in the GADE machine with no accompanying food waste or bacteria. After working for 2 months, the sawdust was sieved with screens of 10, 24, 42, 60, and 100 mesh.

Analysis of physical properties and observation by scanning electron microscopy

Porosity, water retention, and water drainage of raw and residual sawdust were obtained by the methods explained in the previous sections. The morphology of the surface of raw and residual sawdust was observed by scanning electron microscopy (SEM) to determine changes in the structure and other properties of sawdust after use.

Analysis of chemical properties

Hollocellulose, Klason lignin, and extractives contents of raw sawdust and residual sawdust were measured according to standard methods for wood analysis. The carbon, hydrogen, oxygen, and nitrogen elements of raw and residual sawdust and of their Klason lignin were analyzed.

Results and discussion

Physical properties of sawdust

The properties of raw and residual sawdust were measured and compared with those of agricultural soil sampled from the farm of Hokkaido University (Table 1). The apparent specific gravity of sawdust was one fifth lower than that of soil, and the porosity of sawdust was three times that of soil. The WR of sawdust was almost equal to that of soil, and the WD of sawdust was more than that of soil; in fact, one sample of soil did not drain entirely. These results indicate that sawdust, compared with farm soil, is easier to handle and more easily agitated when used as an artificial soil matrix in the GADE machine. These results can contribute to savings in energy consumption.

In todomatsu, karamatsu, and ezomatsu, porosity decreased gradually; and the WR and WD increased suddenly with a decrease in grain size (Table 2). For the larger grains, the WR was small and the WD large; little water was left in the sawdust, because of the amount of space among grains (porosity was large). A contrary tendency was shown for the finer grains. High porosity and small WR are needed for a matrix in the GADE machine to supply air to the aerobic bacteria that degrade garbage. The WR should also be moderate to encourage the multiplication of bacteria. The large grains of sawdust were acceptable in the former, but small grains of sawdust were necessary to the latter. The mixture of sawdust grains showed properties different from those of sieved sawdust; the porosity of the mixture was almost equal to that of large grains, but the WR of the mixture was larger. Therefore it is suggested that blending several grain sizes of sawdust can make it possible to control water retention without decreasing porosity. Based on these results, sawdust composed of wood particles is considered the material most suitable for use as artificial soil in the GADE machine, given that it has the properties of large interspace and intraspace per unit volume, suitable water retention and drainage, and suitable aeration.

Mechanical abrasion of sawdust in GADE machines

The results of the abrasion test in the GADE machine are shown in Fig. 4. It was found that the sawdust had been ground to a finer mesh. The sawdust before and after the wear test and residual sawdust (after use for garbage degradation) were observed with a stereoscopic microscope and a light microscope. Figure 5 shows sawdust of 100 mesh observed by stereoscopic microscopy. The sawdust before operation of the GADE machine was composed of block-shaped particles; after operation it had changed into fibers and residual sawdust. Similar results were obtained using differential interference microscopy (Fig. 6). The sawdust before operation was composed of block-shape particles consisting of several tracheid fibers bunched together, whereas after operation the sawdust was broken into single tracheid fibers, observed as fine fibril shapes (Fig. 6).

Table 1. Physical properties of raw sawdust, residual sawdust, and soil

Material	Moisture content (%)	Apparent specific gravity	Porosity	Water retention	Water drainage ($\times 10^{-3}$ s ml^{-1})
Raw sawdust	10.0	0.16	0.84	0.60	40.0
Residual sawdust[a]	–	–	0.79	0.70	3.1
Soil[b]					
A	25.3	0.80	0.20	0.20	3.70
B	4.6	0.87	0.57	0.55	∞

[a]Residual sawdust was from the garbage automatic decomposer-extinguisher (GADE) machine after use for 3 months

[b]Soil was collected from the farm of Hokkaido University

Table 2. Physical properties of sawdust from todomatsu (*Abies sachaliensis* Masters), karamatsu [*Larix kaempferi* (Lamb.) *Carriére*], and ezomatsu (*Picea jezonensis* Carr)

Material	Moisture content (%)	Apparent specific gravity	Porosity	Water retention	Water drainage ($ml\,s^{-1}$)
Todomatsu					
10 mesh	10.7	0.11	0.84	0.27	293.0
24 mesh	11.1	0.14	0.84	0.45	238.0
42 mesh	11.1	0.18	0.77	0.77	105.0
60 mesh	10.6	0.19	0.76	0.76	5.2
Mixture[a]	10.8	0.14	0.84	0.50	282.0
Karamatsu					
10 mesh	11.2	0.12	0.85	0.23	∞
24 mesh	10.8	0.21	0.82	0.27	251.0
42 mesh	11.1	0.27	0.70	0.70	83.6
60 mesh	11	0.29	0.65	0.65	11.8
Mixture[b]	10.2	0.19	0.70	0.30	132.1
Ezomatsu					
10 mesh	11.8	0.13	0.79	0.25	296.0
24 mesh	11.9	0.15	0.84	0.29	264.0
42 mesh	11.4	0.18	0.77	0.74	105.0
60 mesh	11.4	0.29	0.70	0.70	2.0
Mixture[c]	10.2	0.15	0.81	0.44	126.0

[a]Mixing ratio by volume: 10:24:42:60 mesh = 39:47:10:4
[b]Mixing ratio by volume: 10:24:42:60 mesh = 25:39:21:15
[c]Mixing ratio by volume: 10:24:42:60 mesh = 37:46:11:6

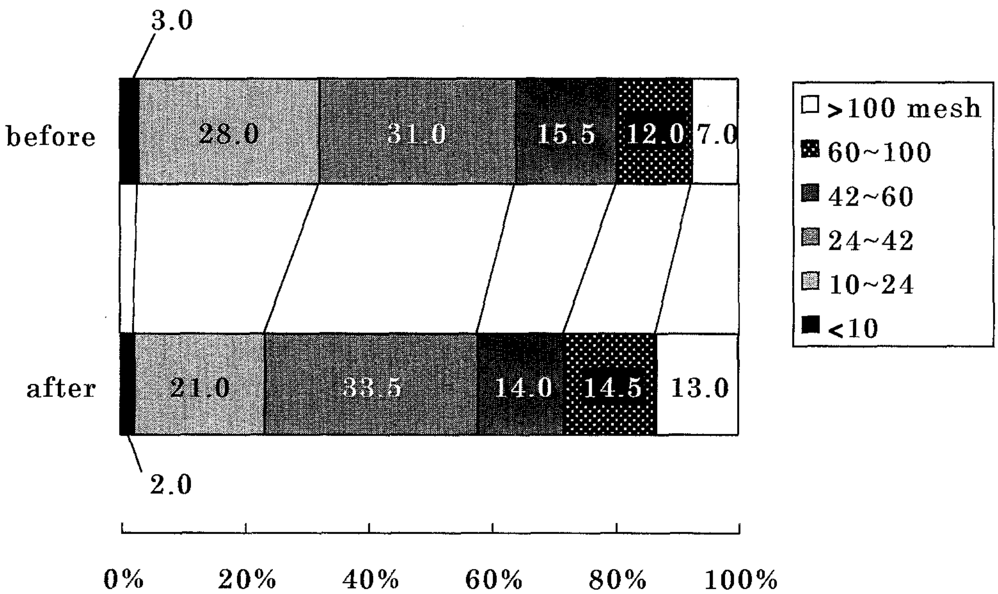

Fig. 4. Grain size distribution of sawdusts before and after working in the gartage automatic decomposes-extinguisher (GADE) machine

Analysis of residual sawdust

The porosity of residual sawdust was almost equal to that of raw sawdust, though its WD decreased markedly during operation of the machine (Table 1). The decrease of WD with no decrease in porosity indicates that residual sawdust had lost its aeration.

The SEM results are shown in Fig. 7. Intermediate degrees of degrading garbage were observed on the surface of the residual sawdust, but the pores of the sawdust were not filled, and space was maintained.

The contents of the water-soluble compounds and hollocellulose in the residual sawdust decreased, but its Klason lignin did not change during the garbage biodegradation process (Table 3). This result indicates that easily degradable polysaccharides such as hemicellulose were degraded, whereas lignin was not. Nitrogen was recognized in the residual sawdust and in its Klason lignin. The garbage is the probable source of the nitrogen.

The above results suggest that reduced water drainage of residual sawdust is due to catabolites from garbage coating the surface of the sawdust grains, not to destruction of the pores. The emission of a foul odor during long-term utilization of sawdust is due to a shortage of oxygen, which is required to degrade garbage aerobically. Therefore, replacing the sawdust after several months' usage is necessary

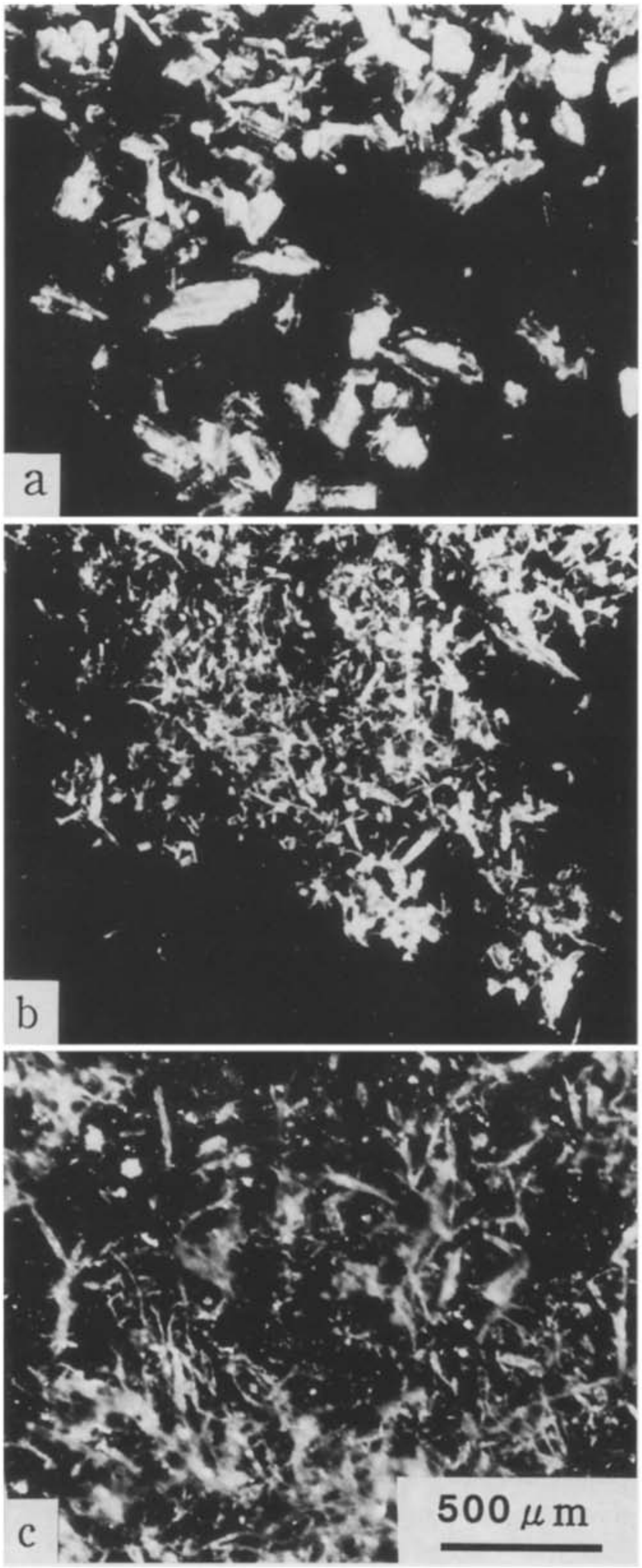

Fig. 5. Sawdust of 100 mesh before (**a**) and after (**b**) operation in the GADE machine and residual sawdust (**c**) examined by steroscopic microscopy

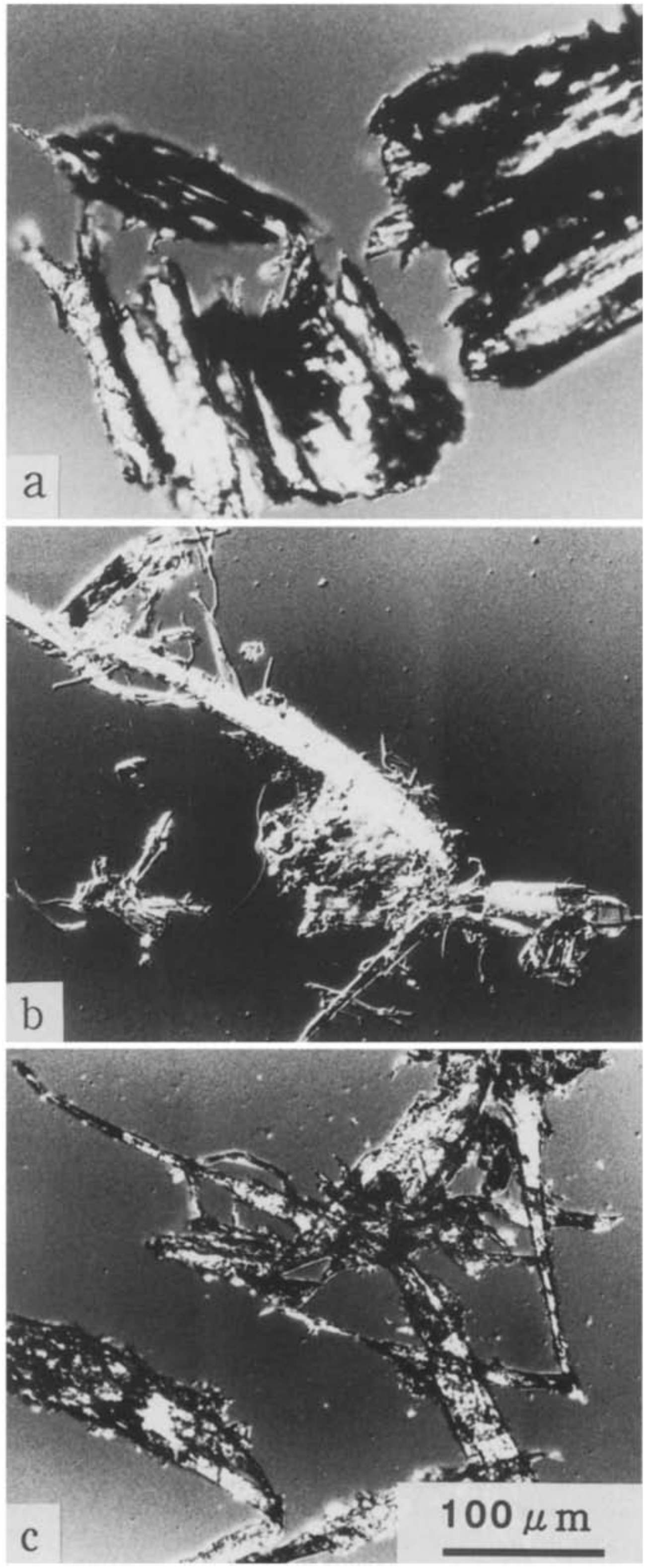

Fig. 6. Sawdust of 100 mesh before (**a**) and after (**b**) operation in the GADE machine and residual sawdust (**c**) examined by differential interference microscopy

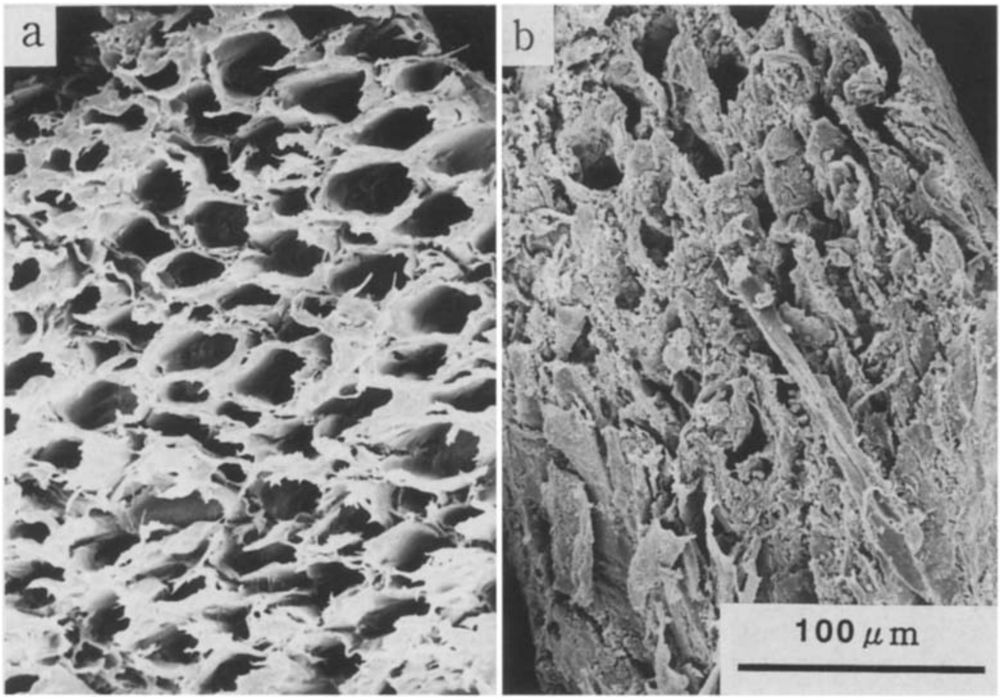

Fig. 7. SEM micrographs of the surface of raw (**a**) and residual (**b**) sawdust

Table 3. Chemical components of raw and residual sawdust

Component	Raw sawdust		Residual sawdust	
	A	B	A	B
Extractives	3.3	–	12.1	–
Klason lignin	29.3	–	29.2	–
Hollocellulose	83.8	–	66.7	–
Carbon (C)	61.58	64.54	60.93	60.08
Hydrogen (H)	5.38	5.75	5.29	5.19
Oxygen (O)	33.04	29.71	32.87	33.83
Nitrogen (N)	0	0	0.91	0.90

A, sawdust; B, Klason lignin obtained from A

to maintain the degrading efficiency of the machine. The residual sawdust may have a secondary use as organic fertilizer or soil conditioner.[2,5,6]

Conclusion

In this study we found that sawdust was suitable for use as artificial soil in the GADE machine because it has a lower apparent specific gravity, larger space per volume, and better drainage than soil. It was also found that physical properties such as porosity, water retention, and water drainage of sawdust differ among grain sizes, and a blend of several grain sizes allows control of water retention without a decrease in porosity. Sawdust without fine grains should be used, and fresh sawdust should be substituted when residue from garbage degradation has accumulated on the surface of the grains.

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