Technical Report

Study on the Densification of Biomass Containing Radioactive Substances: Densification Characteristics of Woody Leaves and Branches

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To decontaminate radioactive substances on agricultural land and in forests, densification experiments using comminution and pelletization on a laboratory were carried out for woody branches and leaves as primal study. Consequently, densification ratios were ranged from 3.5 to 8.6 by comminution and 9.5 to 27 by pelletization. By mixing the woody portion with leaves and branches, the mixed pellet showed sufficient durability as well as reduced radioactive cesium concentration without decreasing the feed rate. A densification test for herbaceous and woody biomass on a larger scale (200 kg/h of feedstock) is underway at Fukushima prefecture, to design the practical plant.

本研究では、除染作業等に伴い発生する、放射性物質で汚染された枝葉、落葉等を安全・安定的にペレットやチップに減容化する技術を開発することを最終目的として、研究所実験林等で収集した枝葉、落葉の粉碎およびペレット成型試験を行い、圧密化(減容化)特性を調べた。その結果、枝葉、落葉の粉碎で3.5～8.6倍(1/3.5～1/8.6)に、ペレット化で9.5～27倍(1/9.5～1/27)に圧密化(減容化)されることがわかった。枝葉、落葉に木部を混合することで、スギ枝葉の実質の供給速度を落とさずに強度的に十分な混合ペレットを製造可能であった。さらに混合物の放射性セシウム濃度は枝葉単独よりも低くなることがわかった。一連の基礎的な検討結果を、福島県にて実施する200kg/h規模の減容化処理実験に反映させ、実プラント建設のための設計値を得ることにしている。

Key Words

Densification, Comminution, Pelletization

1. Introduction

A tidal wave caused by the huge earthquake on March 11, 2011 severely damaged the Fukushima-dai-ichi nuclear power plant, whereupon an explosion causing the release of radioactive substances occurred.

According to a survey of contaminated radioactive cesium in the deciduous and coniferous forests of Fukushima in September 2011, the contamination ratio

of soil and litter (surface soil composed of leaf) exceeded that of leaves and branches of trees in deciduous forests¹⁾. Conversely, nearly half the total cesium remained in leaves and branches, while a third remained in litter for Japanese cedar coniferous forests. This suggests that deciduous forest lacked leaves and that the contamination ratio was lower when radioactive cesium was discharged. Japanese cedar is well-known as an evergreen species, for which cesium is prone to attach to leaves. Furthermore the cesium was contained from the soil surface to a the depth of 50 mm, but at a ratio of less than 10%. Accordingly the radioactive cesium did not penetrate the soil very deeply, suggesting that removal of leaves, branches and litters could be effective in decontaminating radioactive compounds. However the area of decontamination is widespread spread over eastern Japan, and the leaves and branches

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are generally bulky at first; *i.e.* with a lower bulk density compared to the soil and stem. To improve the handling of such bulky biomass and minimize the storage area, densification is a promising method. To densify the material, thermal methods like carbonization^{2,3)}, biochemical methods like fermentation⁴⁾ and physical methods like comminution and pelletization have been proposed. Comminution and pelletization are attractive since they are swifter to process densification and pelletized material (pellet) is easy to handle in a semi-dried state.

In this study, to establish densification more safely and stably for leaves and branches obtained in the decontamination process, comminuting (chipping) and pelletizing were applied as deification methods. The preliminary study involved collecting samples in the Forestry and Forest products Research Institute (Ibaraki and Tokyo).

2. Experimental Details

Japanese cedar (*Cryptomeria japonica*), Himalayan cedar (*Cedrus deodara*) and Japanese zelkova (*Zelkova serrata*) were used as tree species in the Forestry and Forest Product Institute in Tsukuba city, Ibaraki and Hachioji city, Tokyo. For the Japanese and Himalayan cedars, raw leaves and branches were obtained after pruning the whole tree (more than 40 years old), however young whole Japanese cedar trees (less than 5 years old, breast-height diameter of less than 10 cm) were used instead of leaves and branches. For Japanese zelkova, fallen leaves on the roadside in the yard of the institute were obtained as raw material in this study.

The densification was performed by comminution and pelletization. This procedure generally consists of primary comminution, drying, secondary comminution and pelletization. The primary comminution was conducted by a mobile crusher (Ohashi Corp., Japan, GSC-281D, standard comminuting capacity: 5.0 m³/h) while drying was done using an open-type fixed bed dryer (Keneko Agricultural Machinery, HDA180-FHD). The Japanese zelkova was already dried when collected, hence primary drying was omitted. Subsequently, secondary comminution was done using a shear-type comminuting machine (Hokushin Industry Inc., HSK-120) and the moisture content was adjusted to around 15-20% on a wet basis. Then pelletization was conducted using a flat-dye type pelletizer (Kikukawa Enterprise Inc., KP280) at a feeding rate of 10 - 40 kg/h. To evaluate the characteristics of the pellet obtained, bulk density and mechanical durability were employed according to the Quality Standard of the Japanese Wood Pellet Association⁵⁾. However the bulk density of the raw sample

Fig. 1 Mechanical durability testing machine for pellets

for the Japanese and Himalayan cedars was measured by another method. For the Japanese cedar, the value was adopted in literature, while for the Himalayan cedar, the measurement was performed using a commercial 20 L plastic vessel. Fig. 1 shows a machine for testing mechanical durability (Sanyo Trading Co. Ltd.). Each 500 g portion of pellets was placed in the boxes attached to both sides of the instrument, whereupon the pellets were exposed to a rotational force at 50 rpm for 10 min. After rotation, all samples were collected and screened using a sieve with 3 mm round holes. More than 97.5% of the sample remained in the sieve, which met the testing standard. The moisture content varies for each comminuted and pelletized sample. Thus it is necessary to remove the effect of moisture content to evaluate the degree of densification more accurately. In this study the degree of densification was characterized as the bulk density ratio of comminuted or pelletized sample to the raw sample on a dry basis as shown in eq. 1.

Densification ratio (-)

$$= \frac{\text{Bulk density of comminuted or pelletized sample} \times (1 - \text{moisture content (wt\%)}) / 100}{\text{Bulk density of raw sample} \times (1 - \text{moisture content (wt\%)}) / 100} \quad (1)$$

The concentration of radioactive cesium was measured by a germanium semiconductor detector (Canberra corp., GC-2520) for acquisition time of 3600 s.

3. Results and Discussion

Table 1 shows the bulk density and moisture content for comminuted and pelletized samples, the former of which was increased by comminution for each sample. The bulk density after primary comminution was 220 - 300 kg/m³ on wet basis for the Japanese and Himalayan cedars. Subsequent comminution further increased bulk density, up to 310 and 440 kg/m³ for the Japanese and Himalayan cedars, respectively. Although the primary comminution

Table 1 Bulk density, moisture content of samples by comminution and pelletization for the wood species used in this study

Sample	Stage	Bulk density (kg-wet/m ³)	Moisture content (%-wet)	Bulk density (kg-dry/m ³)	Densification ratio (-)
Japanese cedar	Raw sample	130	60.9	51	-
	Primary comminution	220	19.6	177	3.5
	Secondary comminution	310	19.4	250	4.9
	Pelletizing	580	17.0	481	9.5
Himalayan cedar	Raw sample	80	48.2	41	-
	Primary comminution	300	13.2	260	6.3
	Secondary comminution	440	12.4	385	9.3
	Pelletizing	660	11.4	585	14.1
Japanese zelkova	Raw sample	30	19.9	24	-
	Primary comminution				
	Secondary comminution	250	17.6	206	8.6
	Pelletizing	760	14.8	648	26.9

was omitted for the Japanese zelkova, the bulk density was 250 kg/m³ after secondary comminution. The densification ratio on dry basis was also shown in Table 1. The ratios were 4.9, 9.3 and 8.6 for the Japanese cedar, Himalayan cedar and Japanese zelkova, respectively, after secondary comminution. This suggests that comminution can reduce the volume of raw branches and leaves effectively. Furthermore, the bulk densities after pelletizing were 580, 660 and 760 kg/m³ on wet basis and densification ratios on dry basis were 9.5, 14.1 and 26.9 for each sample. This means that pelletizing enabled further densification and

reduced the initial volume by less than one-tenth.

Table 2 shows the mechanical durability of pelletized samples. It was found that the durability exceeded 97.5% for the Japanese cedar and Japanese zelkova, suggesting that the pellets have sufficient durability during handling and storage. However it was also found that insufficient pelletization was conducted when the feeding rate exceeded 10 kg/h for the leaves and branches of Japanese cedar themselves in this study, hence the woody portion was blended with branches and leaves and pelletization was performed (50:50 blend ratio on dry weight). **Table 3** shows the bulk density and moisture content, and **Table 4** the mechanical durability for the woody portion, leaves, and their mixture of Japanese cedar. For the woody portion alone, it was possible to produce pellets at a feeding rate of under 40 kg/h although the

Table 2 Mechanical durability of the pelletized samples

	Japanese cedar	Japanese zelkova
Mechanical durability (%)	98.3	98.2

Table 3 Bulk density and moisture content of comminuted and pelletized samples for the Japanese cedar woody portion, leaves, and their mixture

Species (feeding rate)	Stage	Bulk density (kg-wet/m ³)	Moisture content (%-wet)	Bulk density (kg-dry/m ³)
Woody portion (40 kg/h)	Primary comminution	153	14.3	131
	Secondary comminution	250	9.3	227
	Pelletizing	677	8.1	622
Leaf and branches (10 kg/h)	Primary comminution	179	13.5	155
	Secondary comminution	246	11.7	217
	Pelletizing	580	17.0	481
Mixture * (20 kg/h)	Primary comminution	-	-	-
	Secondary comminution	-	-	-
	Pelletizing	595	14.2	511

* 50/50 wood portion/leaf and branches blend on dry weight

Table 4 Mechanical durability and radioactive cesium concentration of pellets for the Japanese cedar woody portion, leaves, and their mixture

	Woody portion	Leaf and branches	Mixture
Mechanical durability (%)	96.5	98.3	98.6
Radioactive cesium (Bq/kg-dry)	ND	855	340

mechanical durability was slightly under 97.5%. The blended sample enabled mixed pellet to be produced at under 20 kg/h, while the mechanical durability standard was met. This meant it was possible to produce mixed pellets without decreasing the feeding rate of leaves and branches. Table 4 also shows the concentration of radioactive cesium for each sample. The concentration for woody portion received in this study was less than the detection limit (< 11 Bq/kg), while that for leaves and branches was 850 Bq/kg on dry basis. The figure for mixed pellets is between those values (almost half). Mixing the woody portion with a low cesium concentration allowed both stable pelletization and reduced cesium concentration. From the data obtained on a laboratory scale, a larger scale densification plant (feeding rate of 200 kg/h) for herbaceous and woody biomass was constructed in Fukushima prefecture and a densification experiment using the biomass obtained on-site is underway to design on a practical scale.

4. Conclusion

To decontaminate radioactive substances on agricultural land and in forests, densification study involved comminution and pelletization on a laboratory scale for woody branches and leaves was carried out. Consequently, densification ratios were ranged from 3.5 to 8.6 by comminution and 9.5 to 27 by pelletization. By mixing the woody portion with leaves and branches, the mixed pellet showed sufficient durability as well as reduced radioactive

cesium concentration without decreasing the feed rate. A densification test for herbaceous and woody biomass on a larger scale (200 kg/h of feedstock) is underway at Fukushima prefecture, to design the practical plant.

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