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Protocol for Assessing Particle Shape of Comminuted Biomass

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***Abstract*.** Particle shape is increasingly important as a quality parameter for comminuted biomass. Shape affects flowability, pretreatment, rate of conversion, and performance of materials handling systems. This protocol applies to materials that have been subjected to commutation processes including but not limited to chunking, chipping, grinding or milling. Our objective is to enable a uniform terminology and method for characterizing particle shape of chipped, ground, or otherwise comminuted woody biomass. The protocol was specifically developed for chipped and ground woody biomass and may be applicable to other lignocellulosic raw materials and feedstocks. Results are presented for analysis of chipped and shredded forest derived woody biomass.

Keywords. *Biomass, forest, bioenergy, quality, standards*

Introduction

Particle shape is increasingly important as a quality parameter for comminuted biomass. Shape affects flowability, pretreatment, rate of conversion, and performance of materials handling systems. This draft protocol applies to lignocellulosic materials that have been subjected to commutation processes including but not limited to billeting, chopping, chunking, chipping, grinding or milling.

The protocol and definitions were specifically developed for woody biomass: however, it should be readily apparent that the shapes and methods can be applied to agricultural residues, dedicated energy crops, and related raw materials or feedstocks.

Our objective is to enable a uniform terminology and method for characterizing particle shape of chipped, ground, or otherwise comminuted woody biomass.

Safety Emphasis

Biomass particle size and shape affect flowability, bridging, and the frequency of jams in equipment for handling, processing and storage. Human efforts to unjam equipment or break bridging in silos, etc. constitute significant safety hazards. By including particle shape as part of a feedstock or raw material characterization, engineers may be better able to design storage and processing facilities to mitigate the risks posed by particles of high-risk shapes.

Assessment Overview

A sample or representative subsample of material is sorted into shape fractions. The wet weight and dry weight of each fraction are determined and reported. The distribution by particle count for each shape class is determined and reported.

Definitions

Biogeometry - Descriptive shape and dimensions of a biological object such as a wood chip, ground corn stover, etc. where the datum and orientations are determined relative to biological features. For example, in the case of fibrous stalks and woody materials length is always measured along the dominant fiber grain.

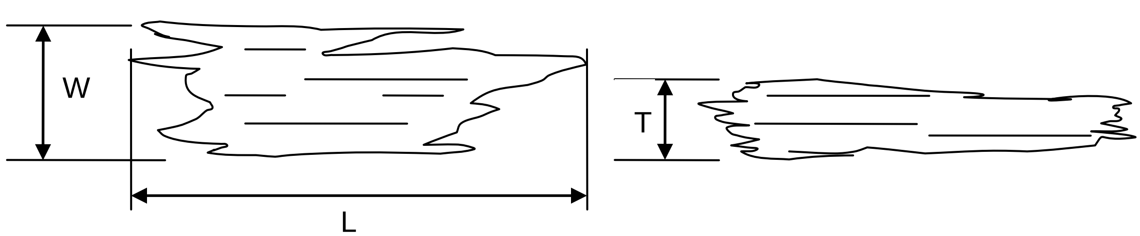

Figure 1. Particle length (L), width (W), and thickness (T) are measured with respect to grain and natural biological structure of the material.

Length (L) – The maximum dimension parallel to grain. For an irregularly shaped particle, length is defined by the minimum distance between parallel vertical faces oriented perpendicular to grain within which the particle will fit. This term may also be called the *extents length*.

Width (W) – The maximum dimension normal to length and perpendicular to grain. For an irregularly shaped particle, width is defined by the minimum distance between parallel vertical faces oriented parallel to grain within which the particle will fit. This term may also be called the *extents width*.

Thickness (T) – The maximum of the third dimension at right angles (normal) to both length and width once the length and width are identified.

Barky – a particle with attached bark on its surface.

Bark length – The length of a piece of bark attached to a barky particle, measured parallel to the wood grain.

Bark width – The width of a piece of bark measured in the same cross-grain dimension as the wood piece width.

Bark thickness – The average thickness of a piece of bark attached to a barky wood piece. Note that this thickness may not be the same orientation as the thickness of the wood piece.

Characteristic Shapes for Woody Biomass Particles

We used a combination of formal focus groups and informal surveys of bioenergy industry association meeting participants to create and understand a lexicon of woody biomass particle shapes. In each case we exhibited a wide range of materials and asked participants to sort them into similar shape classes. We then asked what each class was called in their natural language as well as the defining attributes for each class.

As would be expected there was a wide range of natural language terminology for biomass forms. Some commonalities existed within industry groups such as forest industry fiber buyers, land clearing debris grinding contractors, and power plant operators. We found more commonality across sectors in the technical features that define groups of particles into shape classes.

We sought to create dimensional relationships that could provide a mathematical basis for shape classification. For example, something that most people would call a cube will have a length to width and length to thickness ratio approximately equal to one. Similarly, most people would describe a stick as having a high length to thickness ratio. We also sought to create mathematical relationship sets that would enable shape designation in automated digital image-based assessment systems.

Finally, we sought to group sets of natural language terms into synonyms. The entire multi-year process resulted in our current set of eight shape designators for woody biomass and feedstock particles.

Shape Definitions

- **Fines** (typically defined in the context of the intended use for the biomass feedstock)
    - Defined by sieve size in most cases
    - For coarsely ground or chipped material, fines are those particles that are too small to sort by hand

- **Cubes** (some sawdust fits into this definition)
    - Length : width ratio = 0.7:1 to 1:1
    - Thickness : width ratio = 0.7:1 to 1:1

- **Chips** (micro-chips, pulp chips, whole tree chips)
    - Predominantly cut cross-grain
    - Length : width ratio = 1:1 to 3:1
    - Thickness : width ratio = 0.2:1 to 0.6:1

- **Chunks** (chops, billets)
    - Predominantly cut cross grain to defined length and split with-grain
    - Length : width ratio = 1:1 to 3:1
    - Thickness : width ratio = 0. 5:1 to 1:1

- **Shavings** (flakes, peelings, leaves)
    - Predominantly cut with-grain
    - Length : width ratio = 1:1 to 20:1
    - Thickness : width ratio = 0.05:1 to 0. 3:1

- **Sticks** (shreds, strands, shards, pin chips)
    - Predominantly cut with-grain and having defined or poorly defined ends
    - Length : width ratio = 3:1 to 20:1
    - Thickness : width ratio = 0.2:1 to 1:1

- **Strings** (fibers)
    - Predominantly torn with-grain and typically kinky
    - Length : width ratio = 10:1 to 100:1
    - Thickness : width ratio = 0.05:1 to 1:1

- **Branches/Stalks**
  - Intact segments of stalk, stem or branch
  - Generally round or oval cross section
  - Length : width ratio = 3:1 to 100:1

Example Application of Protocol

Forest Concepts routinely applies this protocol as part of characterizing woody biomass feedstocks. Particle shape and content analysis is frequently done for each sieve fraction after sieve size analyses to determine the differences in shape and content by sieve size fraction.

The example below is from an analysis of "dirty" wood chips evaluated in 2009 (sample ID 2009.11.02.003) and from the fraction that was retained on a screen with approximately 2.5 mm opening. The entire data set includes measurement and shape designation for 570 individual particles. Each particle was measured with a digital caliper. The technician recorded the length, width, thickness, level of bark content, and his or her judgment of shape. The spreadsheet then calculated the ratios of length to width (L:W), length to thickness (L:T), and width to thickness (W:T) as well as particle extents area and particle extents volume.

Table 1. Example data set (partial) for particle shape characterization of woody biomass.

Obs.	Particle Dimensions (mm)				Particle				Particle	Part. Ext.
	Length	Width	Thickness	Barky y/n	Shape	L:W	L:T	W:T	Ext. Area (L*W)	Vol.
1	27	4	2	n	stick	6.8	13.5	2.0	108	216
2	13	6	4	y	branch	2.2	3.3	1.5	78	312
3	17	7	5	n	chip	2.4	3.4	1.4	119	595
4	12	7	4	y	chip	1.7	3.0	1.8	84	336
5	11	7	3	y	chip	1.6	3.7	2.3	77	231
6	25	10	4	n	chip	2.5	6.3	2.5	250	1000
7	25	18	2	y	shaving	1.4	12.5	9.0	450	900
8	23	15	4	n	chip	1.5	5.8	3.8	345	1380
9	19	8	6	y	branch	2.4	3.2	1.3	152	912
10	24	9	3	n	chip	2.7	8.0	3.0	216	648
11	15	9	2	y	shaving	1.7	7.5	4.5	135	270
12	22	7	4	n	stick	3.1	5.5	1.8	154	616

The analysis of all 570 particles enables generation of histograms and pie charts as shown below. Although the material was processed by a disk chipper, only 33 percent of the resulting particles were actually chip shaped. If we add those determined to be chunks and cubes, then the percentage of chips or chip-like particles is approximately 40%. Importantly for those designing materials handling systems, 37% of the particles had shapes more like sticks or branches which suggest that material handling and flowability will be issues.

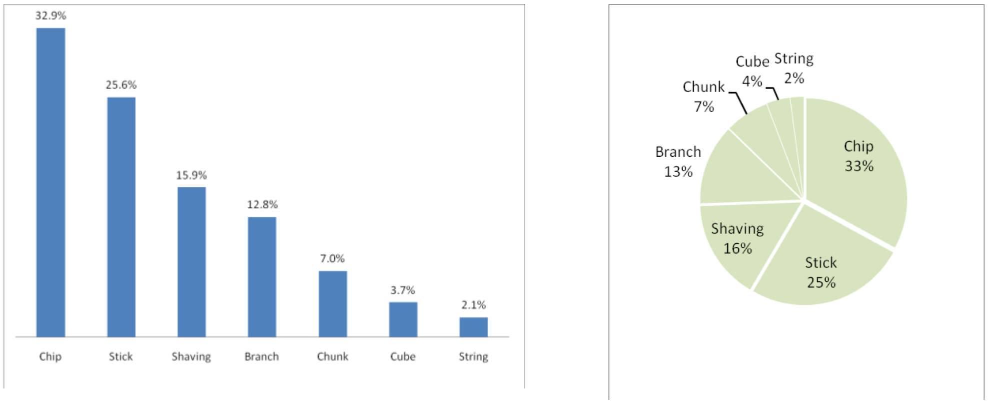

Figure 2. Distribution of particles by shape for chipped woody biomass sample 2009.11.02.003.

This example is based on a data set with 570 particles. More typically, we measure 100-130 particles per sieve fraction to produce operational quality results.

The technical staff at Forest Concepts has done limited work to assess the correlation of our mathematical descriptors that infer particle shape. We find that the mathematical sorting accurately places at least 80 percent of the particles in the “correct” (matches human judgment) shape classification. The percentage correct may be improved in the future by reducing the number of shape classes or by adding additional criteria.

Conclusion

As part of an ongoing effort to characterize biomass feedstocks in ways that inform design, engineering, and operation of biomass supply chain, preprocessing, and conversion facilities, we developed a protocol for assessing particle shape. Particle shape information adds important knowledge not evident from sieve-based particle size analysis.

In this paper, we offer our current protocol for use and improvement by others involved in biomass research and development. There is a need to further refine shape definitions in the context of the implications shape has on design and operation of facilities. There is also a need to further develop automated methods for characterization of biomass material that accurately determine particle shape, size and other important attributes.

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