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Research Paper

Compression and relaxation properties of selected biomass for briquetting

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Compression and relaxation properties of selected biomass for briquetting (barley, oat, canola and wheat straw) were investigated to determine the correlation with variables (pressure, particle size (hammer mill screen size) and moisture contents). The applied pressure ranged from 7.03 to 14.06 MPa. Three hammer mill screen sizes (19.05, 25.40 and 31.75 mm) were used to grind the biomass samples. The ground biomass materials were conditioned to moisture contents of 9%, 12% and 15% (w.b.). The results indicated that the compact density of biomass increased with increasing pressure and moisture content. The relaxation properties of selected materials were affected by the set variables. Biomass materials had a higher stress relaxation speed with higher applied pressure and lower moisture content.

1. Introduction

Mechanical compaction is an effective method to reduce the volume of biomass. Pellets, cubes and briquettes have a higher density than bales or grinds and this gives the compacted biomass advantages in transportation and storage. Also, densified forms reduce wastage and dust compared to ground forms during transportation and use (Johnson, Cenkowski, & Paliwal, 2013). Agricultural biomass, such as barley, oat, wheat and canola straws, commonly used as feedstock for biofuel production, is a viscoelastic material. It is important to understand the rheological behaviour of these materials during compaction in order to optimise compaction equipment design, reduce energy consumption and improve the quality of products (Mani, Tabil, & Sokhansanj, 2004a).

Compaction and relaxation properties of different biomass materials differ depending on the physical-chemical properties and the method of compaction (Mani, Sokhansanj, Bi, & Tabil, 2004). Researchers studying various powder materials have discovered that elastic and plastic deformation occurs during the compression/compaction of viscoelastic materials.

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Nomenclature

a_1	constant
a_2	constant
A	a constant and parameter related to densification of the compact by plastic deformation
A_a	cross-sectional area (m^2)
b	constant
B	a constant and parameter related to powder density at the start of compaction
E_A	asymptotic modulus (MPa)
F_0	initial relaxation force (kN)
F(t)	relaxation force at time t (kN)
k_1	constant
k_2	constant
m	constant
P	applied pressure (Pa)
PR	percentage stress relaxation (%)
R^2	coefficient of multiple determination
RR	decay parameter, stress relaxation rate at t = 1 min (%)
t	time (s)
V	volume of compact at pressure P (m^3)
V_0	volume of compact at zero pressure (m^3)
V_R	packed volume ratio (decimal)
V_S	void-free solid material volume (m^3)
w.b.	wet basis (%)
X_1	weight fractions of components of the mixture
X_2	weight fractions of components of the mixture
Y(t)	a parameter showing the decay of the stress as a function of time *t* (%)
ε	strain (decimal)
ρ	packing density of compact (kg m^{-3})
ρ_1	particle density of component of the mixture (kg m^{-3})
ρ_2	particle density of component of the mixture (kg m^{-3})
ρ_f	packing fraction or relative density of the material after particle rearrangement (decimal)
ρ_r	relative density of the compact (decimal)
σ_0	initial stress, MPa and σ_t stress at time *t* (MPa)
$\sigma_{t=60}$	stress at time t = 60 s (MPa)
$\sigma_{t=240}$	stress at time t = 240 s (MPa)

In general, the densification of materials requires two stages to take place: particle rearrangement and deformation (Faborode & O'Callaghan, 1989, 1987; Kaliyan & Morey, 2009; Mani, Tabil, & Sokhansanj, 2002). In the first stage, particles rearrange bringing themselves closer together and reducing voids; little stress is needed to overcome interparticle and particle-to-wall friction (Mani, Tabil, & Sokhansanj, 2003). The particles retain their properties and elastic deformation mainly occurs during this phase (Cooper & Eaton, 1962). In the next stage, with increasing applied pressure, most of the air is removed from the particulate mass and elastic–plastic deformation of particles occurs (Cooper & Eaton, 1962; Faborode & O'Callaghan, 1989, 1987; Kaliyan & Morey, 2009; Mani et al., 2002; Nona, Lenaerts, Kayacan, & Saeys, 2014). Previous research has developed pressure-density equations to describe the compression characteristics of some metal or non-metallic powders (Cooper & Eaton, 1962; Heckel, 1961; Jones, 1960; Panelli & Filho, 2001; Walker, 1923). These equations may be applied to the compaction behaviour of biomass grinds. Tabil (1996) studied four of these models and showed that the Cooper–Eaton model was the best fit for the compaction of alfalfa grinds. This model was also shown to fit the behaviour of biomass grinds (Mani et al., 2002). The Kawakita-Ludde model had an excellent fit for ground canola, wheat, barley and oat straw materials (Adapa, Tabil, & Schoenau, 2009b).

In commercial briquetting/pelleting, the stress relaxation of compressed material results in an expansion of volume and a decrease in density. After compression, the residual stress in the compressed samples is released. The relaxed density of compressed samples then gradually decreases to a stable value. Relaxation behaviour depends on many factors, such as, the dimensions of briquette, the compression method and the properties of material (Ndiema, Manga, & Ruttoh, 2002). Understanding the influence of these factors is essential in investigating the compression and relaxation of biomass materials during briquetting. The objective of this study is to determine the compaction and relaxation properties of selected biomass materials at different pressures, moisture contents and particle sizes. The specific objective is to fit and develop the compaction and relaxation models with respect to the experimental data.

2. Materials and methods

2.1. Materials

Four biomass (wheat, barley, canola and oat straw) used for the experiments were collected in small bales with dimensions of 0.45 m × 0.35 m × 1.00 m. Canola straw was acquired as small square bales from RAW Ag-Ventures Ltd. (52.67° N, 107.79° W, Maymont, SK, Canada) during the summer of 2013. Wheat, oat and barley straw bales were acquired from the Central Butte area (50.83° N, 106.51° W) of Saskatchewan during the fall of 2013 (Tumuluru, Tabil, Song, Iroba, & Meda, 2014). Wheat, oat and barley straw sample were initially chopped to about 44 mm using a cutter (Model #: CTR, Belfast Mini Mills Ltd., Belfast, PE, Canada). All of the samples were then further ground using a hammer mill (Serial No. 6M13688, Glen Mills, Inc., Maywood, NJ, USA) with screen sizes of 19.05, 25.4 and 31.75 mm (Adapa, Tabil, & Schoenau, 2011).

Each of the ground straws was conditioned to moisture contents of 9%, 12% or 15% (w.b.) by adding appropriate amounts of distilled water to the samples contained in Ziploc bags, and stored in a cool room at 4 °C for 72 h. The moisture contents of the straw samples were measured per ASABE standard S358.2 (2008).

To determine the geometric mean length of ground straw, samples of about 150 g were sieved for 2 min using a screen shaker with sieve sizes 26.9, 18.0, 8.98, 5.61 and 1.65 mm. The