Particuology 12 (2014) 100–106

Contents lists available at ScienceDirect

Particuology

journal homepage: www.elsevier.com/locate/partic

Values for particle-scale properties of biomass briquettes made from agroforestry residues

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ARTICLE INFO

Article history:
Received 15 April 2013
Received in revised form 23 May 2013
Accepted 25 May 2013

Keywords:
Biomass
Briquettes
Mechanical properties
Discrete element method

ABSTRACT

The production of biomass pellets and briquettes from agroforestry residues has increased rapidly in recent years. The design of machines, equipment and the infrastructure necessary for the handling, transport and storage of these products has been an engineering challenge since, when moving, biomass does not usually flow as easily as other granular materials. The discrete element method (DEM) provides a means of studying the handling and silo discharge behaviour of granular solids as well as the distribution of the pressures exerted by such materials in silos. However, the development of such models requires certain properties of the particles in question to be known. The present work experimentally determines the true density, Young's modulus of elasticity (axial and radial), the particle–particle restitution coefficient and the particle–wall friction coefficient—all variables that must be known in the construction of DEM models—for briquettes made from maize stalk, maize stalk plus pine wood chips, rice husk, vine shoots, rape straw, cereal straw and sawdust plus cereal straw.

1. Introduction

The production of biomass pellets and briquettes from agroforestry residues has increased rapidly in recent years (Chen, Li, & Han, 2009; Heinimö & Junginger, 2009; Nilsson, Bernesson, & Hansson, 2011; Parikka, 2004). In 2010, biomass and different types of residues supplied some 8% of all the European Union's energy needs—the equivalent of some 118 million tonnes of oil (AEBIOM, 2013). This contribution is likely to increase since it has been decreed that at least 20% of the European Union's energy demand must be met by renewable resources by 2020. By this time, some 20 million ha of land are likely to be producing energy crops (European Parliament and the Council of the European Union, 2009).

The great quantity of biomass to be produced in the future will require appropriate machinery, equipment and infrastructure for its handling, transport and storage (Bernhardt, 2005). However, the design of such machinery and systems faces the problem that, when moving, biomass does not flow as easily as other types of granular materials (Barletta et al., 2012; Khan, Bradley, & Berry, 2006; Larsson, Thyrel, Geladi, & Lestander, 2008; Miccio, Barletta, & Poletto, 2012; Miccio, Silvestri, Barletta, & Poletto, 2011). Furthermore, the properties (e.g., true density, water content and durability) of different types of biomass product may vary considerably, in accordance with the design of a range of handling, transport and storage solutions.

The behaviour of granular solids can be predicted using advanced numerical analysis techniques, such as the finite element method (Gallego, González-Montellano, Ramírez, & Ayuga, 2011), the discrete element method (DEM) (González-Montellano, Ayuga, & Ooi, 2011), and computational fluid dynamics. These techniques can also be used to determine the behaviour of biomass during handling and storage. Such knowledge can help avoid some of the problems encountered in installations, such as corrosion, obstruction, wear and breakage, caused by the presence/movement of the biomass.

The DEM is a numerical technique specifically designed for the analysis of the behaviour of granular materials, which include biomass pellets and briquettes. The method is based on an explicit numerical procedure in which the interactions between particles, and between particles and the wall of their containers, are monitored contact-by-contact, and in which the movement of the granular solid is modelled particle-by-particle (Cundal & Strack, 1979). The practical applications of this include the analysis of silo discharge processes (Chung & Ooi, 2008; González-Montellano, Ramírez, Gallego, & Ayuga, 2011), analysis of the distribution of the pressure exerted by the stored material on the walls of the

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1674-2001/$ – see front matter
http://dx.doi.org/10.1016/j.partic.2013.05.007

Fig. 1. Samples of the biomass briquettes examined (except cereal straw): (1) vine shoots, (2) rape straw, (3) rice husk, (4) maize stalk, (5) sawdust and cereal straw, and (6) maize stalk mixed with pine wood chips.

containing vessel (Masson & Martínez, 2000), and the simulation of the handling of granular materials (Boac, Casada, Maghirang, & Harner, 2010; Mellmann & Teodorov, 2011; Owen & Cleary, 2009).

The construction of DEM models requires certain properties of the material in question to be known. Only then can particle–particle and particle–wall contact be simulated. These properties include the axial and radial moduli of elasticity, the Poisson' ratio, the true density of the particles, the particle–particle restitution coefficient, the particle–wall restitution coefficient, the particle–particle friction coefficient and the particle–wall friction coefficient. However, the experimental determination of the values of these properties at the individual particle level is not always easy.

Biomass briquettes are a form of solid biofuel made by compressing lignocellulose residues at high pressure and temperature. While the literature includes many reports on the properties and behaviour of briquettes and pellets with respect to combustion (Lindström, Larsson, Boström, & Öhman, 2010; Smit & Meincken, 2012; Suhartini, Hidayat, & Wijaya, 2011), only a few papers have reported the determination of some of the above properties for biomass or agroforestry residue (Chung, Ooi, & Favier, 2004; González-Montellano, Fuentes, Ayuga-Téllez, & Ayuga, 2012; Mani, Tabil, & Sokhansanj, 2006; Mohsenin, 1970; Wong, Daniel, & Rongong, 2009). Indeed, none have examined the particle–particle or particle–wall restitution coefficients, or the axial or radial moduli of elasticity of such materials. The aim of the present work was thus to experimentally determine the values of the particle-scale properties of briquettes made from agroforestry residues required for the construction of DEM models able to predict their dynamic behaviour.

2. Materials and methods

2.1. Materials

The compacted materials used to make the briquettes (supplied by FERRO S.A.) studied in the present work were maize stalk plus pine wood chips, rice husk, vine shoots, rape straw, sawdust plus cereal straw, maize stalk and cereal straw. Fig. 1 shows the briquettes examined. All were cut transversally to produce cylinders 30 mm in height, and these were then cut transversally to obtain the sample 'particles' used in the assays described below.

The experimental protocols followed and the equipment used were basically those described by Chung et al. (2004) and Wong et al. (2009), adapted for use with biomass briquettes.

2.2. Methods

2.2.1. Particle true density

The true density (ρ_p) of the briquette particles was determined using the mercury intrusion porosimetry. The total volume of the examined briquette samples (n = 10–15 of each type, randomly selected) was determined via the mass of mercury displaced upon immersion in a levelled, mercury-filled vessel (Fig. 2). The mass of each briquette particle was determined using a precision balance. Other methods could have been followed (González-Montellano et al., 2012; Rabier et al., 2006), such as the direct measurement of the mass of the briquette particles using a precision balance and the estimation of their volume via approximation to known standard volumes. A pycnometer method (ASTM D854-10, 2010) is also available; once the mass of a particle is known, its volume is determined by immersion in a known volume of water in a graduated vessel. However, these procedures present problems such as the approximation of the shape of the particle to known volumes, or the water penetrating the briquette matrix. The mercury immersion technique was therefore deemed better suited for use with the present particles.

Fig. 2. Mercury-filled vessel used to determine the true density of the particles.