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Research article

Mechanical degradation of biomass wood pellets during long term stockpile storage

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ABSTRACT

This paper quantifies and assesses the mechanical degradation of white wood and steam exploded wood pellets in indoor and outdoor stockpile storage over a twenty-one month period in the UK. The indoor stored steam exploded wood pellets on the surface of the pile only exhibited a 3% decrease in durability after twenty months in storage. The outdoor stored pellets demonstrated much higher levels of mechanical degradation. In the summer period with high relative humidity and temperature, the durability of pellets sampled from the surface of the pile dropped from 92 to 22% after three months in storage with a durability of 10% measured after nine months in storage. The degradation of the pellets from the middle of the pile was more gradual and less severe with a maximum durability drop of 34%. The impact on mechanical properties was significant for the indoor stored white wood pellets with pellets quickly degrading to dust. This study shows that while steam exploded pellets could be stored in covered storage, white wood pellets require a fully enclosed storage environment. Short term outdoor storage of steam exploded pellets could be considered if extended periods of low rainfall and relative humidity can be reliably predicted.

1. Introduction

The large scale use of biomass worldwide in decarbonising power generation is predicted to grow in order to meet the EU 2030 emissions targets of 40% below 1990 levels and renewables target of providing at least 27% of EU's energy requirements [1]. Densified pelletized forms of biomass fuel are preferred as they have higher energy density and hence provide an economic advantage in the areas of transport, storage and handling. However, compared to coal, wood pellets bring a number of challenges in areas of supply [2], storage and transport [3–6], conveying and milling [7] and combustion [8]. Burning wood pellets can also result in changes in the ash and emissions composition which will have to be considered in treatment processes downstream of the burner [9,10]. Occupational health and environmental considerations are also important [11].

One of the challenges in storage and transport is the loss of pellet mechanical integrity. A significant loss of mechanical strength can lead to high levels of dust, which increases the risks of fires and explosions [12,13], as well as posing a health hazard to workers [14]. Higher dust levels also potentially cause heat generation in stockpiles by microbial attack as explained by Lehtikangas in [15].

There are studies reported investigating the changes in the pellet mechanical properties as a result of storage [15–17], however these are at much smaller scale than typical utility industry fuel stores. Lehtikangas [15] investigated the small scale storage of nine different types of pellets made from fresh and stored sawdust, bark and logging residues. Storage took place in large plastic bags in an unheated barn for 5 months from December to May in Sweden. The range of tests carried out included moisture and ash content, heating value, pellet length, bulk density, durability, water absorption resistance and particle size distribution. The changes in the chemical properties of the pellets were not significant but storage resulted in break-up of the pellets, as reflected in the reduced pellet length and pellet durability. Chico-Santamarta et al. [16] also reported on pellet length reduction when storing canola straw pellets in airtight bags in a storage shed at Harper Adams University College, UK for 48 weeks while Kymalainen et al. [17] observed a decrease in the pellet durability of untreated wood pellets, torrefied pellets and steam exploded pellets stored over a period of five months in 0.5–1 l mesh bags in both outdoor uncovered and covered storage in Finland.

The work reported here differs from these previous works in that the storage was at a significant scale (~6 tonnes/metric tons) and in stockpiles and replicated the potential storage scenarios being considered by power generators within the UK – i.e. outdoors and in covered facilities. This comprehensive study investigated the impacts of relative humidity, ambient temperature and rainfall separately and collectively on the

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moisture uptake and mechanical degradation of white wood and steam exploded wood pellets in stockpile storage. Pellets from both the surface and middle of the different piles were sampled at regular intervals with photographs and SEM images of the degraded pellets generated and presented within this paper. Mechanical tests performed on the samples enabled axial and diametrical compression strengths and the inter-laminar shear modulus to be determined as well as durability. The range of laboratory tests undertaken also included the determination of the pellets' volatile and ash content and net calorific value as well as the fungal count and identification on fresh and degraded samples. However, the analysis and results for these aspects are not included here, more information can be found in Graham [18]. As part of this long term study, a short term project was carried out in the laboratory to investigate the effects of relative humidity and temperature on wood pellet degradation as reported by the same authors in [19].

2. Material and methods

Two different pellet types and two different storage scenarios were studied over different periods as listed below:

- Steam exploded wood pellets (20 months, spring to the following winter) indoor (covered roof) and outdoor storage
- Steam exploded wood pellets (12 months, winter to winter.) outdoor storage – this was a different batch of pellets to the one above
- White wood pellets (10 months, autumn to autumn) indoor (covered roof) storage.

The steam exploded wood pellets (made from a mixture of softwood and hardwood chips) were sourced by E.ON from an American supplier. Storage trials were carried out promptly upon delivery of the pellets to the UK. The white wood pellets were manufactured from softwood material (again originally supplied from North America) and sourced by E.ON from Ironbridge power station, it should be noted that they had previously been stored at Ironbridge for a few months in a fully enclosed warehouse. The properties of the fresh steam exploded pellets as received in the first and second batches for storage in the spring and winter respectively and the fresh white wood pellets for autumn storage are listed in Table 1.

The pellet stockpiles were constructed at Leyfields farm in Retford, UK, owned by Coppice Resources Ltd. [20]. All of the stockpiles had the same size 2.4 × 2.4 m base by 1.5 m high, corresponding to approximately 6 t (metric tons) with the perimeter being established by a permeable porous membrane enclosure. The pile height was restricted by the angle of repose of the pellets, which was <45°. In the first spring, two steam exploded wood pellet piles were constructed, one indoor (Fig. 1a), and one outdoor (Fig. 1b), both on concrete bases; these were monitored over twenty months in storage. The indoor pile was constructed in an open barn which had a roof and two walls, being open on the remaining two sides. This constituted Phase 1 of the project. In the autumn, a white wood pellet pile was set up for indoor storage in the open barn and studied for 10 months. In the winter, a new outdoor steam exploded wood pellet pile was also built and studied for 12 months. This constituted Phase 2 of the project.

The temperatures within the stockpiles were continually monitored and logged as were the ambient temperature, rainfall and relative humidity using a weather station at the site [18]. The total rainfall was measured as height in mm per unit area captured at the storage site. A tipping bucket rain gauge was used which registered a pulse of 0.13 mV for every 3 cm^3 of water collected in the bucket, which corresponded to 0.091 mm depth of water per unit area. The rainfall in mm per unit area could therefore be calculated from the voltage recorded.

Fuel samples (approximate sample size of 500–600 g) were extracted from the surface and middle of each storage pile on a monthly basis for the first six months and then less frequently thereafter using a graded sampling probe (Fig. 2) which was specially designed for this task [18].

The probe was made of a polycarbonate material and 2 m in length with internal and external diameters of 9.4 cm and 10 cm respectively. As shown in Fig. 2, the sampling section only constituted a small part of the probe and was designed as a fully enclosed section with a trap door. It had an aperture of 6 cm wide and 14 cm long. A stainless steel rod and handle were connected to the sampling section. After the probe had been inserted to the right location inside the pile where sampling could take place, the handle was turned to open the trap door and allow sample to fall into the sampling section. The trap door was then closed again prior to the sampling probe being extracted out of the pile. The probe was also graded so that the depth reached within the pile could be monitored. The surface sample was taken on the surface of each pile and 75 cm from the ground (halfway up pile) and the middle sample was taken 75 cm from the ground and approximately 1.2 m (halfway) into the pile horizontally. The collected samples were not pre-treated prior to the analysis and testing mentioned in this article.

The pellet % moisture content was determined using the oven drying method using British Standard DD CEN/TS 15414-2:2010 [21]. The moisture content reported in this paper is on a wet basis. Drying at 105 °C [21] was only carried out on 300 g of each monthly sample once. The weight of each sample taken from the piles monthly was kept at around 500-600 g to try and avoid too much material being removed from the piles, potentially causing movement of material within the piles. However sample variation for the moisture test was determined at the start and end of the storage period and the maximum sample variation range was 1%.

2.1. Pellet images

Photographs of the pellets from both the surface and middle of each pile were taken at regular intervals. Scanning electron microscopy (SEM) was carried out on the cross section of the pellets to better understand crack formation and propagation within. SEM images were acquired at the point of receipt of pellets (denoted as 'fresh' throughout) and after 3 and 6 months in storage. The microscope used was a Quanta 600 by FEI [22]. Before SEM analysis, samples were set in epoxy resin and polished [18].

2.2. Measurement of mechanical properties

2.2.1. Pellet durability

The pellet durability of fresh and stored samples was measured using a Dural (II) tester [23]. A 100 g sample of pellets was tumbled at 1600 rpm for 30 s and then sieved through a 4.75 mm sieve. Typically

Table 1
Properties of fresh pellets at the start of storage.

Pellet	Bulk density kgm^3	Average diameter mm	Average length mm	Net calorific value kJ/kg	Moisture content %	Volatile content %	Ash content %
Steam exploded batch 1 Phase 1	780	5.8	17.1	18,710	2.7	72.6	2.9
Steam exploded batch 2 Phase 2	750	6.2	21.1	19,247	3.2	73.5	1.1
White wood pellets Phase 2	615	8.2	16.3	17,375	9.2	72.0	1.6