Comparison between diametral and uniaxial compression tests of pelleted feed

Carlos Salas-Bringas[1], Nevena Mišljenović[2], Odd-Ivar Lekang[1] and Reidar Barfod Schüller[3]

[1]Dep. Of Mathematical Sciences and Technology, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway

[2]Faculty of Technology, University of Novi Sad, Bulevar C. Lazara 1, 21000 Novi Sad, Serbia

[3]Dep. Of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway

ABSTRACT

Diametral compression tests are a common method in feed technology, however the applied stresses and the stresses producing failure in feed pellets with a ductile nature is difficult to be estimated from a diametral test. This study investigates the convenience of using uniaxial compression tests.

INTRODUCTION

Different types of compression testing machines have been used over the years in testing single particles[1]. A significant advantage of compression testing over traditional durability devices is that the applied forces and often the deformations can be recorded during the test in order to determine the load-deformation profiles. Consequently the material properties and behaviour can be obtained.

Besides the extended use of durability devices at feed plants, diametral compression tests are also used by feed technologists to determine the strength of a batch of feed pellets. Conversely uniaxial compression tests are not used in feed technology, the reason is probably due to the cylindrical pellets produced by pellet presses do not have sharp and defined ends as they are broken and not cut by knives. If pellets do not have a defined end, the uniaxial test becomes difficult since the pellets should stand by themselves vertically, the other inconvenience when testing a pellet in uniaxial position having irregular ends, is that the stresses applied by the texture analyzer could be concentrated on small local regions and not throughout the entire pelleted mass.

The creation of pellets with defined and sharp ends has been achieved in the laboratory pelleting equipment developed and utilized by Salas-Bringas et al.[2-4] which is used to manufacture feed pellets under controlled conditions of temperature and stress. As a consequence, the strength of the pellets produced in this equipment can be study in both diametral and uniaxial tests.

Generally speaking, it is desired when measuring a material strength to be able to determine the strength independently of the shape and size of the specimen been tested. This can be ideally obtained by knowing the area where the stresses are concentrated when the material exhibits failure. In ductile materials like pelleted feed[5] this is however very difficult to obtain because the pellets present an unknown number of cracks before the major failure occur (maximum peak force). It is then more reliable to measure the strength by considering the area of the applied stresses. In uniaxial tests the area of applied stresses correspond to the circular area of the cylindrical pellet. However the advantage of the uniaxial test to determine the applied stresses compared to diametral tests, it is important to use the method that can provide the less dispersion or variance as possible of the applied forces since it should represent the strength of a pelleted material. Also a low variance indicates the repeatability of the testing method.

Consequently the purpose of this study was to compare the variance between the forces applied in uniaxial and diametral compression test for pelleted feed.

Additionally, the influence of the length to diameter (L/D) ratio on the applied forces was investigated.

MATERIALS AND METHODS

Raw material

Ground wheat was obtained from the Centre for Feed Technology pilot plant (FôrTek), which belongs to the Norwegian University of Life Sciences, Ås, Norway. The wheat grains were ground in an 18 kW hammer mill having a 3 mm mesh (Münch-Edelstahl, Wuppertal, Germany).

The moisture content of the ground wheat was determined by drying for 20 hours in an oven (Termomax, Norway) at 105 °C.

Pelleting method

All pellets used in this research were produced in the laboratory die pelleting rig presented by Salas-Bringas et al[3, 6]. The rig was assembled in a Lloyd LR 5K Plus texture analyzer. This equipment has been previously used to produce wood pellets[3, 6]. The die pelleting rig consists of a barrel made of brass having a compressing channel along the centre. The compressing channel has a diameter of 5.5 mm and a 5.4 mm diameter rod was used to press the samples against a blank die. Using this configuration, the system can produce compacting stresses up to 218 MPa. To release the pellets from the compressing channel, the blank die was disassembled from the barrel.

The barrel was heated by a jacket heater of 550 W which is controlled by a PID connected to a thermocouple in the barrel surface.

Production of pellets

Before pelleting, ground wheat was stored from 2 to 3 weeks in sealed plastic bags at room temperature. Four groups of 50 pellets were made for the strength tests. Two groups were made with a length to diameter ratio (L/D) around 1 and the other two groups having an L/D around 2.

Two different quantities of sample were added into the compressing channel to produce the two different L/D groups of pellets. Once the ground wheat was added into the compressing channel, a compressing rod was placed at the top of the channel and kept at this position for one minute in order to heat the sample and avoid moisture losses. The temperature was set to 82 ºC. 81 ºC is the minimum temperature that is required in Norway[7] to disable *Salmonella* and to reduce the number of bacteria. However, the feed industry normally uses a minimum of 82 ºC as an assurance, the reason why it was chosen this temperature in our experiments.

After the heating period, the ground wheat was compressed using a normal stress of 10.92 MPa (equivalent to 250 N force) with a compressing speed of 0.5 mm s^{-1}. 10.92 MPa of compressive stress was chosen to match the density of rich in wheat pellets produced in the semi-industrial pellet press located at FôrTek pilot plant (1.2 ton/h maximum capacity). The selection of the mentioned compressive stress is further discussed in Salas – *Bringas* et al[8].

Following the compressing stage, the pressure was released, the blank die was removed and each pellet was gently pushed out from the channel using the same compressing rod driven by the Lloyd LR 5K texture analyzer.

Before performing the strength measurements, the pellets were stored in plastic bags at room temperature for about 24 hours to even out the temperature of the surface and core.

Measurement of pellet strength

The strength of the pellets under diametral and uniaxial compression (see Fig. 1) was determined by using the maximum peak force during the compression test. The length, diameter and weight of each pellet were measured with a digital calliper and a scale, respectively. The compression tests were performed using a probe with a flat surface of 60 mm in diameter (shown Fig. 1) which was connected to the same Lloyd LR 5K texture analyzer, the same testing arrangement has been used in previous research[3].

The compressing speed was set to 1 mm min^{-1} and the test was ended after the main ductile rupture of the pellet (max. peak force).

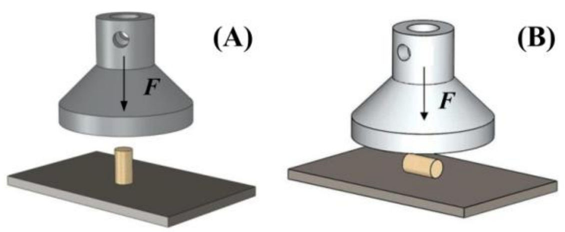

Figure 1: Uniaxial (A) and diametral (B) tests of feed pellets. *F* represents the force applied by the Lloyd LR 5K texture analyzer used in this research.

Data analysis

To compare the dispersion of the strength results between diametral and uniaxial compression, a test for equal variances (F test) was performed in Minitab software (Minitab Inc, USA) to all groups.

RESULTS AND DISCUSSIONS

Production of pellets

The only significant differences ($p < 0.05$) in density among the four groups were between L/D ≈ 1 and L/D ≈ 2. It can be seen in Fig. 2 a small decrease in density as the L/D ratio increases from ~1 to ~2 in the pellets manufactured with the same compressive stress. The reason for these changes in density can be explained by the friction between the material and the side walls of the channel (or die) which reduces the compressive stress along the pellet during manufacture[3]. Consequently the pellets will have a lower density at the opposite side of the applied force, reason why the longer pellets (L/D ≈ 2) presented a lower density. It is also likely that these pellets will present a larger density gradient throughout the length, or in other words a density change from one side to the other.

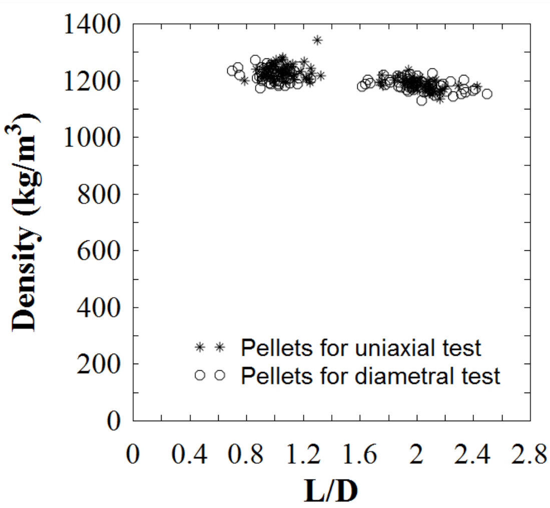

Figure 2: Density and L/D (length to diameter ratio) for the four groups of pellets. A significant ($p < 0.005$) decrease in density ($kg\ m^{-3}$) was found from L/D ~1 to L/D ~2 for the pellets manufactured with the same compressive stress from the rod.

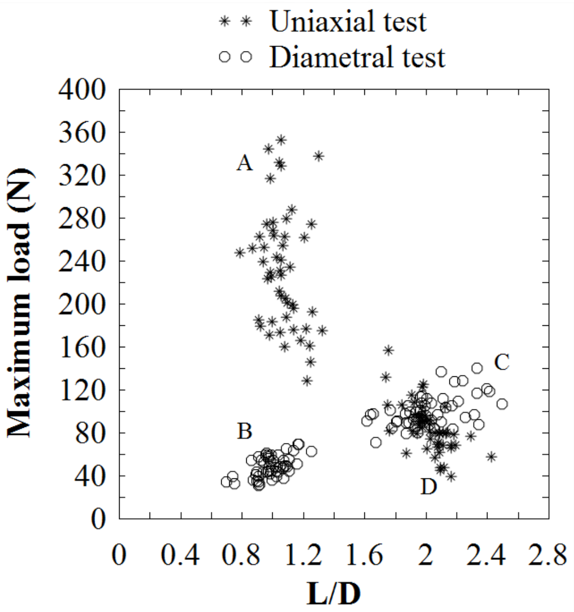

Figure 3: Maximum load for the four groups of pellets during the strength tests. Different letters indicate significant differences ($p < 0.005$) among the means.

The differences in strength measured through the maximum load (N) in diametral and uniaxial compression can be seen from Fig. 3. From this figure is possible to observe how the L/D ratio affects the maximum load. For pellets tested under diametral compression, a higher L/D resulted in a significantly ($p < 0.05$) higher maximum load. This can be explained as a higher L/D provides a higher area, A ($A = L \cdot D$), to distribute the forces, resulting in lower stresses, τ ($\tau = F/A$), where F is the applied load.

Conversely to the effects of L/D under diametral test, the uniaxial tests resulted in the opposite relation between L/D and the maximum load. This can be explained by the effect of length on the distribution of forces leading to changes in compression and buckling.

Generally speaking, if the load on a column is applied through the center of gravity of its cross section, it is called an axial load. A short column under the action of an axial load will fail by direct compression before it buckles (e.g. small L/D), but a long column loaded in the same manner will fail by buckling (bending). The buckling effect can be so large that the effect of the direct load may be neglected. The stress-strain behaviour of materials is not strictly linear for ductile materials as these pellets even below yield. In these materials the modulus of elasticity decreases as stress increases, with more rapid change near yield. This lower rigidity reduces the buckling strength of the pellet structure and causes premature buckling. Consequently buckling and ductility effects together can explain the reasons for having lower maximum loads as L/D increases from only 1 to 2.

Table 1: Differences between variances for the uniaxial and diametral tests. P-values were calculated from an F test.

Strength tests	Variance	L/D	p-value*
Uniaxial	3018	~1	0.000
Diametral	102	~1	
Uniaxial	527	~2	0.002
Diametral	211	~2	

* p-value represents the differences within a group of L/D.

As it can be seen in Table 1, the variance of the maximum load for both groups of pellets (L/D ≈ 1 and L/D ≈ 2) tested in diametral compression, resulted to be lower than the variance of strength measured in uniaxial test. This can also be observed from the dispersion of the data points shown in Fig. 3. Consequently, from these results it can be concluded that the average strength obtained in diametral test represents better the material strength of the pellets compared to the strength measured in uniaxial test. A small variation in strength results is sought when a test value should represent a group of pellets.

CONCLUSIONS

This study concludes that the average pellet strength obtained in diametral compression test is more representative to pelleted material than the uniaxial test method due to lower variance.

The maximum load producing breakage is affected by L/D ratio. In diametral tests, a larger L/D produces a larger maximum load and the opposite is found for uniaxial tests.

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