Compression characteristics of alfalfa cubes

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Patil, R.T., Sokhansanj, S., Khostaghaza, M.H. and Tabil, L.G., Jr. 1996. **Compression characteristics of alfalfa cubes**. Can. Agric. Eng. **38**:195-200. The mechanical properties of alfalfa cubes influence their chewability and durability. Penetration with cylindrical probe, point load bending, and compression were selected to test the mechanical characteristics of cubes. For penetration and bending tests, the load deformation relationship was expressed as modulus of deformability and modulus of rupture, respectively. For compression test, the overall strain was measured. The effect of crosshead speed, probe size, and orientation of cubes for testing mechanical properties indicated that only probe diameter is an important factor. The method of penetration with the cylindrical probe of 7.9 mm diameter at crosshead speed of 20 mm/min was found suitable to specify relative hardness of alfalfa cubes.

Les propriétés mécaniques des cubes de luzerne influencent la résistance à la dent et la durabilité des cubes. Des tests de pénétration avec une sonde cylindrique, de compression et flexion dus à une charge ponctuelle ont été faits afin de déterminer les caractéristiques mécaniques des cubes. La relation entre la charge appliquée et la déformation pour les tests de pénétration et de flexion furent respectivement exprimés en terme de module de déformabilité et module de rupture. Pour les tests de compression, on a mesurer la déformation générale. Les effets de la vitesse de traverse, du diamètre de la sonde et de l'orientation des cubes lors des tests ont été examinés. Il semble que seul le diamètre de la sonde soit un facteur important. Le test de pénétration avec une sonde de 7.9 mm de diamètre à une vitesse de traverse de 20 mm/min permet d'évaluer adéquatement la dureté relative des cubes de luzerne.

INTRODUCTION

Alfalfa is an important forage crop in North America. The cubes are long fiber products made from alfalfa chopped in about 50 mm lengths. The cubes are presently graded unofficially and subjectively according to their color and fibre quality. The hardness and durability of the cubes are important mechanical characteristics which could be used to grade them numerically. ASAE standard S269.4 (ASAE 1993a) specifies a method to determine the durability of cubes. Howes (1973) measured the hardness of hay wafers based on ASTM D 143 - 94 method (ASTM 1995). A ball of 11 mm in diameter was penetrated into the wafer to one half of its diameter and the force at this point was recorded as hardness. The hardness of wafers decreased with an increase in moisture content.

Despite the fact that the term is widely used in general, no definition of hardness exists for forage cubes. Similar to food materials, the hardness of cubes may be expressed in terms of firmness (Stroshine et al. 1992; Jackman et al. 1990; Mohsenin 1986; Robbins and Sjulin 1986; Jindal and Techasena 1985; Mizrach et al. 1985). Hardness can also be related to the chewability or palatability of a forage cube by livestock.

The great variability in the quality of a forage product is due to maturity of the raw material at the time of cut and other agronomic practices. The continually changing process parameters during manufacturing make the technique of hardness testing of cubes difficult. For the development of a standard method for testing cubes, consideration has to be given to the desirability of adopting available methods that would yield consistent results.

A hardness property established for cubes can provide data for use in development of grading rules and specifications and can predict their acceptability by different livestock. Hence, the objective of the present study was to compare some methods of compressive loading to determine their suitability for measuring the relative hardness of alfalfa cubes.

MATERIALS AND METHODS

Two sizes of cubes, a regular cube with a cross-section of 35 mm x 35 mm and a large cube with a cross-section of 35 mm x 72 mm, were tested. Figure 1 shows a standard size cube. The Instron universal testing machine with computerized data acquisition system was used (Model 1011, Instron Corporation, Canton, MA). The data on load versus deformation were collected at the rate of 10 points/s by Instron Series IX Automated Materials Testing System software package (Version 5.2) (Instron 1991).

Fig. 1. A regular alfalfa cube with a cross section of 35 x 35 mm.

Test parameters

A preliminary test was performed to determine the test parameters in a penetration test such as crosshead speed (loading rate), probe size, and orientation of the cube. The sample size was 15 cubes for each run. Table I lists the experimental design.

The density of the cubes was measured by method of dimensional measurement proposed by Sokhansanj et al. (1991). The significant difference between the cube densities was tested by analysis of variance. The test parameters finalized in this experiment were used in further compression tests.

Categories of cubes

The cubes were remoistened to three levels of moisture content that produced the three levels of hardness. The regular and large cubes originally had moisture contents of 7 and 11.3% wet basis (wb), respectively. The cubes were placed in an environmental chamber at 22°C and relative humidity of 90% for up to 36 h. The moisture content increase was determined from the difference in initial and final masses of the cubes.

Table I: Factorial experimental design to determine test parameters in penetration test

Variables	Levels
Independent	
Crosshead speed	15 and 25 mm/min
Probe size	6.4, 8, and 9.5 mm diameter
Orientation of cube	flat surface and ribbed surface*
Dependent	Crushing strength (N)

* The cube is extruded through the cuber and it develops two surfaces along its length; one plain surface and another ribbed surface where 2 halves of the die join.

Penetration test

This test was based on the ASAE standard S368.2 (ASAE 1993b) for compression test of food materials of convex shape. In this method the penetrating tool (a probe of 7.9 mm diameter with flat end) was mounted on the testing machine. The simultaneous readings of load and penetration were taken until after the rupture point. The rupture point as an index read from the load deformation curve, described the stiffness of the material (ASAE 1993b). The rupture point was defined as the point on the force deformation curve at which the loaded specimen shows a visible failure in the form of cracks. This point is detected by a continuous decrease of the load in the force deformation diagram.

The modulus of deformability was calculated as:

$$E = (F/A)/(\Delta l/l) \quad (1)$$

where:

E = modulus of deformability (MPa),
F = force at failure point (N),
A = area of the probe (mm^2),
Δl = depth of penetration of probe (mm), and
l = thickness of the cube (mm).

Based on the results in the preliminary experiment, the crosshead speed was kept at 20 mm/min. The cube rested on the flat side and the probe was placed at the center of the upper surface. The load at crushing or failure was recorded (Fig. 2, setup B).

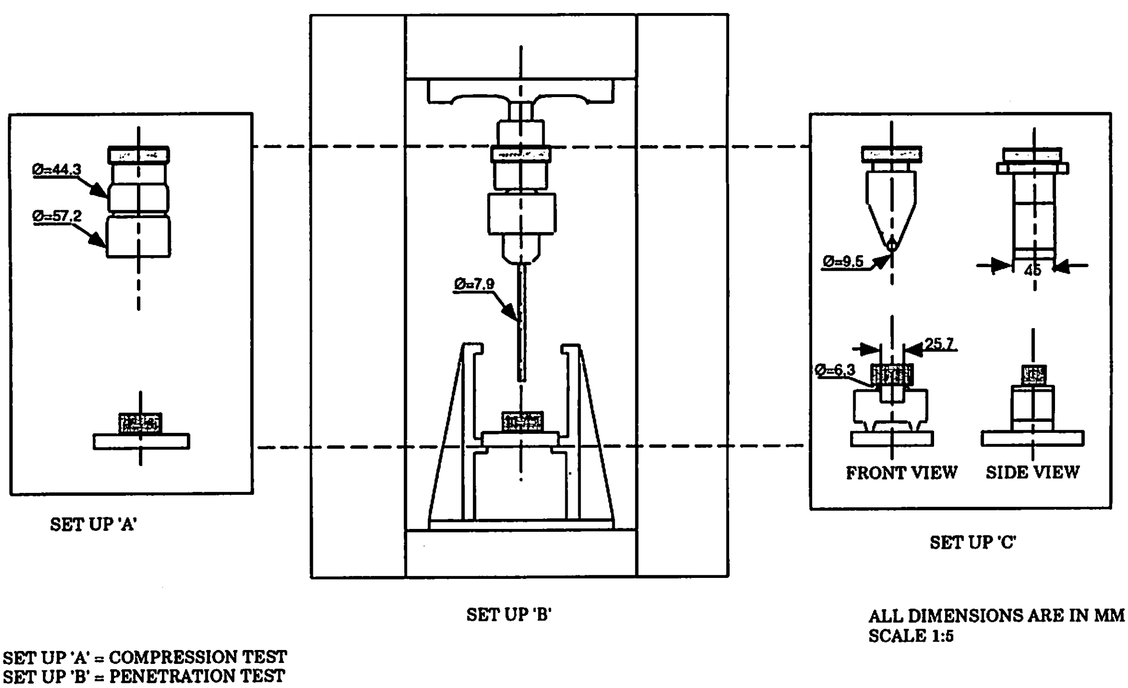

Fig. 2. Schematic diagram of the set ups used in compression studies.

Bending test

This test method was based on the ASTM C 133-84 test used for determining the modulus of rupture of refractory brick and shapes (ASTM 1992a). The test jig, as shown in Fig. 2 (setup C), was used for determining the modulus of rupture of the cubes. This test emulated the manual testing of the cubes when a person breaks a cube at the center with the pressure of thumbs. The cube was supported lengthwise at two points on bearing cylinders of 6.3 mm diameter and 45 mm length at a span of 32 mm. The force was applied by crosshead speed of 20 mm/min with a horizontal cylindrical rod of 9.5 mm diameter and 45 mm length. The cube was broken in mid-span and the rupture force was recorded. At the rupture point the cube showed a visible failure in the form of cracks.

The modulus of rupture by this method was calculated as:

$$MOR = 3\,F\,L\,/\,2\,b\,d^2 \qquad (2)$$

where:

MOR = modulus of rupture (MPa),
F = concentrated force at rupture (N),
L = span between supports (mm),
b = width of cube (mm), and
d = depth of cube (mm).

Compression under specific load

This test was similar to ASTM D 575 standard for rubber products in compression (ASTM 1992b). This method is useful in comparing stiffness of material in compression. The cubes were subjected to loads up to 750 N at a crosshead speed of 20 mm/min and percent deflection was recorded (Fig. 2, setup A). In the preliminary experiment on deciding the specific load level, it was found that 500 N did not show a sizable deflection for comparison and at 1 kN about 20% of the cubes were broken. Hence a mid level of 750 N was selected for this study. The cubes were subjected to compression on the plain surface of the cubes.

Number of cubes for each test

The number of specimens tested for hardness was decided according to ASTM D 3108 (ASTM 1992c). The sample size was calculated from:

$$N = (t\,v)^2/A^2 \qquad (3)$$

where:

N = sample size,
t = value of student's t for two sided limits at 95% probability level and infinite degrees of freedom, 1.96 (for population),
v = estimate of coefficient of variation, CV, and
A = 15% of average, the value of allowable variation.

At 35% CV (as given in Table II) the sample size (N) came to 22 hence for each test 25 cubes were used.

The data were analyzed by PROC GLM of the SAS (SAS 1985) package for analysis of variance. Duncan's multiple range test was used to compare the individual means at P = 0.05. The criteria to choose the best method among the three methods was the lowest CV and the highest value for F statistic.

Table II: Effect of loading rate, probe size, and application surface on force required to rupture the cube

Probe size (mm)	Surface	Loading rate (mm/min)	Force (*N*)	S.D. (*N*)	CV (%)
6.35	1*	15	240	70	29.2
	1	25	260	40	16.7
	2**	15	230	90	40.8
	2	25	310	80	25.6
7.87	1	15	330	110	33.2
	1	25	300	110	36.0
	2	15	300	140	47.0
	2	25	300	110	36.5
9.65	1	15	370	190	50.8
	1	25	320	110	35.9
	2	15	370	130	34.0
	2	25	460	180	39.8

1* = plane surface, 2** = ribbed surface
S.D. = standard deviation
CV = Coefficient of variation

Table III: Analysis of variance and error analysis for compression test parameters

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Model	3	0.45	0.15	9.98	0.0001
Error	166	2.47	0.015		
Corrected Total	169	2.92			
PROBE	1		0.422	28.33	0.0001
FACE	1		0.020	1.32	0.2522
SPEED	1		0.012	0.81	0.3680

RESULTS AND DISCUSSION

The initial moisture contents of the cubes as received from a manufacturing plant were 7 and 11.3% wb for regular and large cubes. The three moisture contents which were adjusted were 7, 12.6, and 15.4% wb for regular cubes; and 11.3, 15.6, and 18.5% wb for large cubes. The variation in the cube density was not significant at P = 0.01, for the cubes used in this study. The density of the cubes tested was 740 kg/m^3.

The results of the experiment conducted to decide test parameters are given in Tables II and III. Table II gives the ultimate force required to break the cube with the penetration test at different loading rates, surfaces, and with different probe sizes. The results indicate that the crushing force increased with loading rate and with an increase in probe size.

The coefficient of variation of the mean ranged from 29.2% to 50.8%. The high and wide variation may be due to the fact that cubes are produced from a mixture of leaves and stems by repeated compression. The particle size of the material compressed varies, hence, the finished product is a heterogeneous solid with large differences among cubes from the same lot.

The analysis of variance of these data indicated that the effect of probe size was significant (P = 0.01), whereas other factors such as orientation of the cube and crosshead speed between 15 and 25 mm/min did not have a significant effect. The interactions of the test variables also did not show significant effect on the crushing strength. Hence, for further studies the crosshead speed of 20 mm/min and flat surface were selected.

Compression tests on regular cubes

The results of all three types of tests on regular cubes are given in Table IV. The average load deformation curves for penetration and bending test for regular cubes, as obtained by plotting raw data by the Instron Series IX Automated Materials Testing System software package (Version 5.2), are given in Figs. 3 and 4. The average absolute loads for failure in the case of the penetration test and in the case of the bending test are given. The force requirement for failure in bending was much higher than that required for penetration. The modulus of deformability and modulus of rupture calculated by these methods showed a significant difference between cubes with low and medium moisture content. The third test method of measuring the percent deflection under specific load showed clear distinction between the cubes at three levels of moisture content.

Table IV: Results of compression tests on regular cubes

Type of test	F value	CV	Cube moisture content (% wb) 7	12.6	15.4
Puncture (N)	6	38	242[a]	229[a]	169[b]
Modulus of deformability (MPa)	19	28	4.55[a]	3.41[b]	2.86[b]
Bending (N)	8	46	389[a]	353[a]	199[b]
Modulus of rupture (MPa)	8	46	0.44[a]	0.40[b]	0.23[b]
% Strain under 750 N	22	21	12.59[a]	15.52[b]	18.96[c]

Means with the same letter in a row are not significantly different at P = 0.05

Compression tests on large cubes

The results of all three types of tests on large cubes are given in Table V. The average load deformation curves for penetration and bending methods for large cubes are given in Figs. 5 and 6. The force required at failure was significantly different for cubes at 11.3 and 15.6% moisture levels. However, there was no significant reduction in strength when moisture was increased to 18.5% moisture content. The parameter of modulus of deformability failed to show the difference between cubes with low and medium levels of moisture content. The method of percent deflection under specific load also could not show the difference between low and medium moisture cubes.

Selection of the method for cube hardness

The method of penetration with the cylindrical probe is simpler to adopt because it does not require the specific sample preparation for testing. The ordinary universal testing machine can be used to conduct this test. Hence, this method could be followed for testing the cubes for their relative hardness measurement. The method of percent deflection under 750 N loading though showed distinctive property for small cubes, it re-

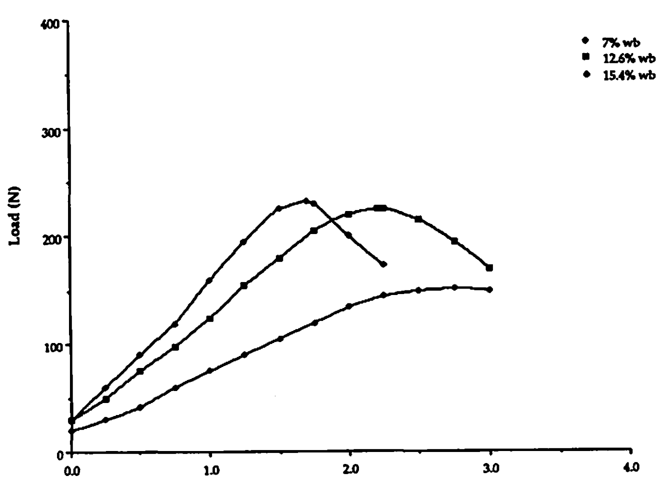

Fig. 3. Average load deformation curves for penetration tests on regular cubes at different moisture contents.

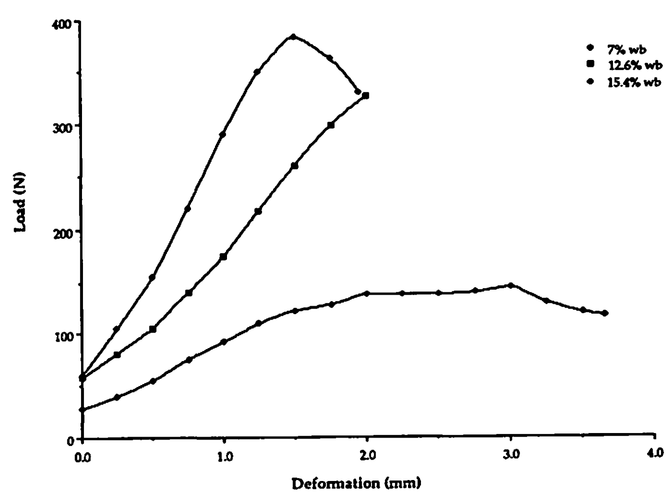

Fig. 4. Average load deformation curves for bending tests on regular cubes at different moisture contents.

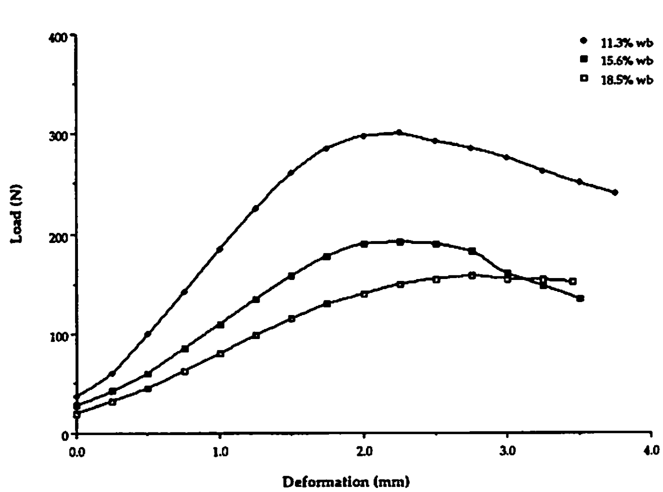

Fig. 5. Average load deformation curves for penetration tests on large cubes at different moisture contents.

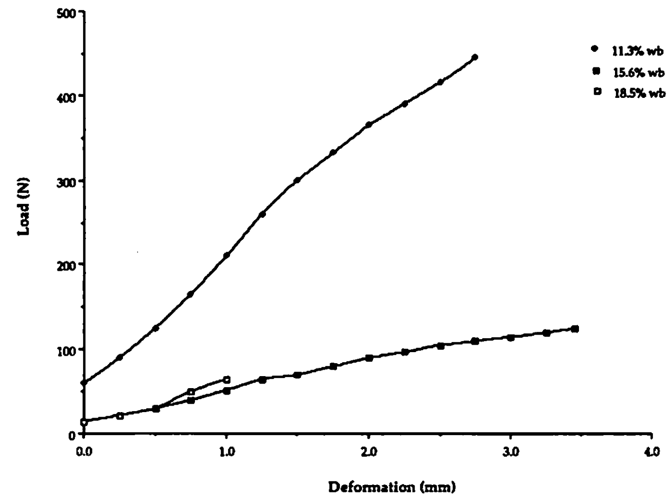

Fig. 6. Average load deformation curves for bending tests on large cubes at different moisture contents.

quires precise sample preparation having the same cross sectional area and thickness, as well as precise measurement of deformation which may be complex and cumbersome for rapid testing of cube hardness. Looking to these facts, the method of penetration was recommended for testing hardness of cubes with 7.9 mm diameter probe at 20 mm/min loading rate.

Table V: Results of compression tests on large cubes

Type of test	F value	CV	Cube moisture content (% wb) 11.3	15.6	18.5
Puncture (N)	11	53	341[a]	211[b]	183[b]
Modulus of deformability (MPa)	38	21	4.49[a]	4.22[a]	2.60[b]
Bending (N)	9	79	420[a]	163[b]	117[b]
Modulus of rupture (MPa)	11	62	0.41[a]	0.19[b]	0.13[b]
% Strain under 750 N	69	17	11.51[a]	12.44[a]	19.56[b]

Means with the same letter in a row are not significantly different at P = 0.05

CONCLUSIONS

From this study, the following conclusions were drawn:

1. For determining hardness of alfalfa cubes, the probe size was the only parameter which affected the strength observations.
2. For grading alfalfa cubes for their relative hardness, the method of penetration with 7.9 mm diameter probe may be followed for 25 cubes. For both the indices, absolute force required at failure and the modulus of deformability may be given.

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