World Applied Sciences Journal 6 (8): 1028-1032, 2009
ISSN 1818-4952

Bending and Shearing Properties of Wheat Stem of Alvand Variety

[1]A. Esehaghbeygi, [2]B. Hoseinzadeh, [2]M. Khazaei and [1]A. Masoumi

[1]Department of Farm Machinery, College of Agriculture,
Isfahan University of Technology, Isfahan, 84156-83111, Iran
[2]College of Agriculture, Shahrekord University, Shahrekord, 115, Iran

Abstract: Shearing stress of wheat stalk was measured for four moisture content levels (15, 25, 35 and 45%, w.b.), three cutting heights (100, 200 and 300 mm), two types of cutting knives, smooth and serrated edge and three blades oblique angle (0, 15 and 30 deg.). The results of data analysis showed that the shearing stress of wheat stems decreased as the moisture content decreased. The shearing force of stems, decreased as the cutting height of stalk increased, because of a reduction in stalk diameter. Shearing stress was lower by using smooth edge knife, because of less friction than serrated one. The blade oblique angle of 30 degree showed the least shearing stress. The average of shearing stress varied between 3.25 and 3.86 MPa. Bending stress and modulus of elasticity increased as the moisture content decreased and decreased as the cutting height of stem increased. The average of bending stress varied between 17.74-26.77 MPa and modulus of elasticity varied between 3.13-3.75 Gpa.

Key words: Wheat · Shearing stress · Bending stress · Modulus of elasticity

INTRODUCTION

Increasing interest in harvesting and commercial use of wheat straw has prompted the need for engineering data on straw properties. Most studies on the mechanical properties of plants have been done during their development using failure criteria (force, stress and energy) and the Young's modulus [1, 2]. The physical properties of the cellular material are important for cutting, compression, tension, bending, density and friction [3, 4]. Persson [5] reviewed several studies on the cutting speed and concluded that cutting power is only slightly affected by cutting speed between 1.72-5.2 m s^{-1}. Majumdar and Dutta [6] studied the required shearing energy for two varieties of rice and a variety of wheat in cutting speeds of 2.53 and 4.5 m s^{-1} and edge angle of 20 and 40 degrees, by using a Pendulum type impact shearing device. Analysis of the data showed that the effects of crop type and edge angles on shearing energy were significant. Ince *et al*. [7] stated that it was necessary to determining the stem physic-mechanical properties such as bending and shearing stress and energy requirements for suitable knife design and operational parameters. Measurement of the shearing strength of six varieties of wheat straw by O'Dogherty *et al*. [8] showed mean values in the range of 5.4-8.5 MPa. Kushwaha *et al*. [9] reported mean values of shearing strength of wheat straw from 8.6 to 13 MPa with some dependence on moisture content. Other workers have measured the energy require to shear materials. Mcrandal and McNulty [10] evaluated the shearing strength of grasses stem with quasi-static shear test. They studied the effect of shearing velocity, at 15, 28 and 41 mm min^{-1}, bevel angle, at 10, 30 and 45 degree and diameter of stems. They found that shearing velocity and bevel angle did not have significant effects on shearing strength but their interaction had significant effect at 5% probability level. Prasad and Gupta [11] determined the shearing force and energy for cutting maize stem. They resulted that maximum shearing strength and shearing energy in the direct shear test were observed to decrease with the shearing velocity. Sakharov *et al*. [12] reported that the required force to cut the stretched stalks was 50% less than that of unbent stalks. Chen *et al*. [13] found that the average values of the maximum force and the total cutting energy for hemp were 243 N and 2.1 J, respectively. Chattopadhyay and Pandey [14] determined the bending stress for sorghum stalk as 40.53 and 45.65 MPa at the seed stage and forage stage, respectively. Ince *et al*. [7] determined the bending stress and Young's modulus for sunflower stalk as 37.7 to 62.09 MPa and 1251.28 to 2210.89 MPa, respectively. There are a few studies on

Corresponding Author: Dr. A. Esehaghbeygi, Department of Farm Machinery, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran

bending stress of wheat stem and lack of information about Young's modulus. The present study was conducted in order to determine the shearing stress or maximum shear strength of Alvand wheat stem as a function of cutting height, moisture content, knife type and oblique angle of cutting knife. Also bending stress and modulus of elasticity of stem as a function of moisture content and height of stem was determined.

MATERIALS AND METHODS

To determine the average moisture content of the wheat stems on the date of the test, the specimens gathered from the field were weighed and dried at 103°C for 24 h in the oven and then reweighed [15]. A complete randomized block design was used in a factorial experiment with three replications using the statistical packages SAS10 and MINITAB15. Means were compared using Duncan's multiple range tests ($p<0.05$). The values of independent variables discussed in the study are detailed in Table 1.

Shearing Test: In order to determine the shearing force of wheat stems, an experimental shearing apparatus with a commercial single sickle knife section and a countershear were used as the double shear test. This simulated a single edge cutting process of a reciprocating knife of the cutterbar under a constant speed of 200 mm min^{-1}, with a Hounsfield universal testing machine under a load cell 5 kN. Shearing stress of the stem was determined by dividing the shearing force into two section areas of the stem sides as Eq. (1) [16].

$$\tau = \frac{F_{Smax}}{2A} \tag{1}$$

Bending Stress and Young's Modulus: The stiffness of stalks encountered during harvesting depends on the rigidity of materials (E). The deflection and rigidity in

Table 1: Dependent and independent variables studied in the research

Dependent variables	Independent variables	Values
Shearing stress	Moisture content, % w.b.	15, 25, 35, 45
	Cutting height, mm	100, 200, 300
	knife type	Smooth and serrated
	Oblique angle of	edge knife
	cutting knife, deg	0, 15, 30
Bending stress	Moisture content, % w.b.	15, 25, 35, 45
	Stalk height, mm	100, 200, 300
Modulus of elasticity	Moisture content, % w.b.	15, 25, 35, 45
	Stalk height, mm	100, 200, 300

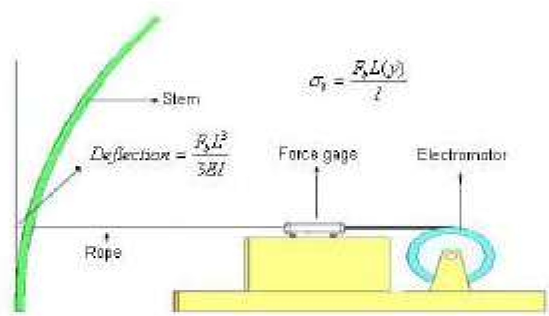

Fig. 1: Measuring method of stem bending force

bending under load can be determined by the cantilever test [7]. Selected stems in the field were tied at a height of 100, 200 and 300 mm using an inelastic rope connected horizontally to a digital force gauge. The stems were then bent by pulling the rope (Fig. 1). On reaching a 50 mm deflection at the tying point, the bending force (F_b) was recorded from the gauge indicator and the bending stress (σ_b) was calculated from theoretical Equation [7]. Young's modulus was assessed using deflection equation in bending test similar to those described [7, 17].

RESULTS AND DISCUSSION

The analysis of variance showed that cutting height, moisture content, knife type and oblique angle of knives and the interactive effects of knife type and oblique angle had significant effect on stem shearing stress at 1% probability level. Treatments effectiveness on shearing stress or coefficient of determination of main factors, sum of squares in analysis of variance table divided by total sum of squares were 55%. The data also revealed that the effect of moisture content and cutting height had significant effects on bending stress and modulus of elasticity at 1% probability level. Moisture content and stem height had the coefficient of determination of 70% and 38% that means treatment effectiveness on bending stress and modulus of elasticity, respectively.

Effect of knife type and oblique angle on stem shearing stress: Greater engagement of the serrated edge knife with the stem than smooth one and the increase of friction were the main causes to increase shearing stress by 7% (Fig. 2). These results did not in agreement with Chen *et al*. [13] for hemp stems but match the results obtained by Persson [5] and Khazaei *et al*. [18], who reported significant differences in the total cutting energy values between smooth and a serrated blade. Comparing the three blades oblique angles (0, 15 and 30 degrees), the 30-degree one had the lowest while the 0-degree oblique

Table 2: Effect of oblique angle on stem shearing stress

Oblique angle (deg.)	Shearing stress (MPa)
0	3.92a
15	3.58b
30	3.36c

*Different letters shows significant difference, Duncan 5%

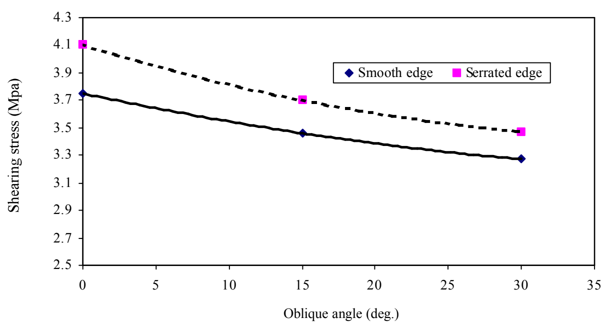

Fig. 2: Effect of knife type and oblique angle on stem shearing stress

angle had the maximum force requirements (Table 2). The effects of oblique angle can be explained by the change of contact area between the knife and the stem while cutting has accrued and by the physical properties of stem tissues. The relation between shearing stress in MPa and oblique angle by using smooth and serrated edge knives could be found as Eq. (2) and Eq. (3), respectively.

$$\tau_{smooth} = 3.75 - 0.2A + 0.002A^2 \quad (R^2{=}0.98) \qquad (2)$$

$$\tau_{serrated} = 4.1 - 0.03A + 0.003A^2 \quad (R^2{=}0.96) \qquad (3)$$

Where, A= Oblique angle (deg.)

Effect of Moisture Content on Stem Shearing Stress: The value of shearing stress at low moisture content was approximately 19% lower than at high moisture contents. This result was also reported for wheat straw, sunflower stalk and alfalfa stem [8, 7, 16]. The average shearing stresses were found 3.25, 3.57, 3.69 and 3.86 MPa for moisture contents 15%, 25%, 35% and 45% w.b., respectively. The moisture content had a significant effect on the shearing stress at 1% probability level (Table 3). An exponentially relationships, between shearing stress and moisture content, reported by previous researchers [10]. Eq. (4), (5) and (6) shows relation between shearing stress, (ô) and moisture content, %w.b., (MC) at the stem cutting height of 100, 200 and 300 mm, respectively.

Table 3: Effect of moisture content on stem properties

Moisture content (%w.b.)	Shearing stress (MPa)	Bending stress (MPa)	Modulus of elasticity (GPa)
15	3.25c	26.77a	3.75a
25	3.57b	20.57b	3.57b
35	3.69b	19.20bc	3.46b
45	3.86a	17.74c	3.13c

*Different letters in each column, shows significant difference, Duncan 5%

Table 4: Effect of cutting height on stem properties

Cutting height (mm)	Shearing stress (MPa)	Bending stress (MPa)	Modulus of elasticity (GPa)
100	3.80a	21.14a	3.81a
200	3.62b	20.21b	3.50b
300	3.35c	17.85c	3.12c

*Differentletters in each column, shows significant difference, Duncan 5%

$$\tau_{H100} = 4.15 + 0.001MC - 0.003MC^2 \quad (R^2{=}0.96) \qquad (4)$$

$$\tau_{H200} = 3.95 + 0.002MC - 0.003MC^2 \quad (R^2{=}0.97) \qquad (5)$$

$$\tau_{H300} = 3.61 + 0.002MC - 0.003MC^2 \quad (R^2{=}0.96) \qquad (6)$$

Effect of Cutting Height of Stem on Shearing Stress: The shearing stress was decreased with increasing of cutting height (Table 4). This result was also reported by others [7, 16]. In terms of plant height, most of the wheat varieties were statistically significantly different from each other [19]. With increasing the cutting height from 100 to 300 mm, shearing stress will be reduced by 13%. With increasing the stem height, stem diameter will be decreased in the range of 5.1 to 7.5 mm.

Effect of Moisture Content and Cutting Height of Stem on Bending Stress: Moisture content had a significant effect on bending stress at 0.05 probability confidence. Bending stress decreased with increasing moisture content (Fig. 3). This result was also reported for wheat straw and sunflower stalk [1, 7]. The moisture content and height had significant effects on bending stress at 0.05 probability confidence. The value of bending stress at low moisture content was approximately 1.5 times higher than at high moisture content (Table 3). The average values for the bending stress were found to be 17.74, 19.2, 20.57 and 26.77 MPa for moisture contents of 45%, 35%, 25% and 15% w.b., respectively (Table 3). Eq. (7), (8) and (9) shows the relation between bending stress and moisture content in the stalk height of 100, 200 and 300 mm, respectively.

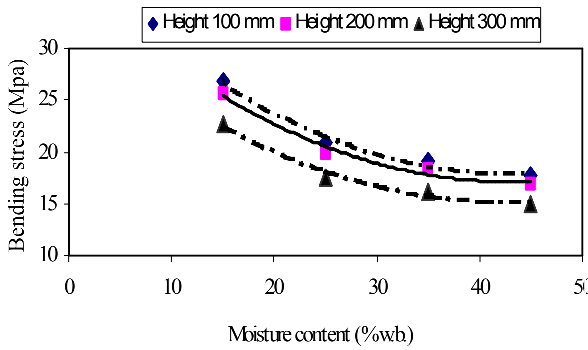

Fig. 3: Effect of moisture content and cutting height on stem bending stress

$$\sigma_{b-H100} = 74.01 + 56.12\cos(0.02MC + 2.27) \quad (R^2=0.96) \qquad (7)$$

$$\sigma_{b-H200} = 70.50 + 53.40\cos(0.02MC + 2.27) \quad (R^2=0.98) \qquad (8)$$

$$\sigma_{b-H300} = 62.25 + 42.10\cos(0.02MC + 2.27) \quad (R^2=0.98) \qquad (9)$$

Where, σ_b= Bending stress (MPa)

Effect of Moisture Content and Cutting Height on Young's Modulus: Moisture content had a significant effect on modulus of elasticity at 0.05 probability confidence. The modulus of elasticity decreased with increasing moisture content and stems diameter (Fig. 4). With increasing the stem height, stem diameter be decreased. This result was also reported by other workers [7, 16]. The difference between the values for the modulus of elasticity at the lowest and highest moisture contents was about 18% w.b. The average values for the modulus of elasticity were found to be 3.13, 3.46, 3.57 and 3.75 GPa for moisture contents of 45%, 35%, 25% and 15% w.b., respectively. The effect of moisture content and height of stem on the modulus of elasticity was significant at 0.05 probability confidence. O'Dogherty *et al*. [8] had shown that the Young' modulus of wheat stem reduced 4.76 to 6.58 GPa, when internodes moisture increased. Eq. (10), (11) and (12) show the relation between the modulus of elasticity and moisture content at the stalk height of 100, 200 and 300 mm, respectively.

$$E_{H100} = 2.50 + 2.10\cos(0.01MC + 0.42) \quad (R^2=0.96) \qquad (10)$$

$$E_{H200} = 2.01 + 1.80\cos(0.02MC + 0.11) \quad (R^2=0.98) \qquad (11)$$

$$E_{H300} = 1.95 + 1.86\cos(0.01MC + 0.40) \quad (R^2=0.98) \qquad (12)$$

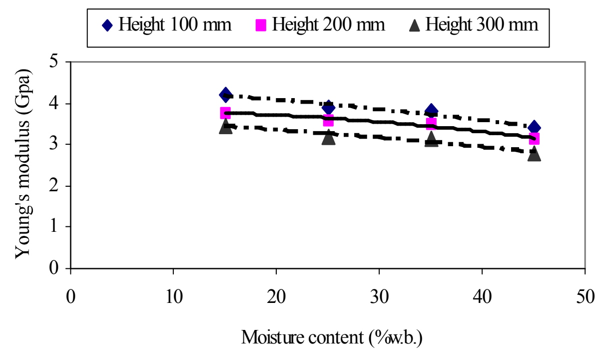

Fig. 4: Effect of moisture content and cutting height on stem Young's modulus

CONCLUSIONS

As the cutting height of the wheat stalk increased, shearing force of stalk decreased because of reduction in stalk diameter. The average of shearing stress varied between 3.25 and 3.86 MPa. Taller plants, however, have lower stem diameters and shearing energy will be decreased. Shearing stress is lower by using the smooth edge, because of less friction than serrated one. The oblique angle of 30 degree showed the least shearing stress. Selection of knife type plays a significant role in economizing on cutting force requirements. So selection of suitable oblique angle of the knife decreases the shearing force of wheat stems. The shearing stress, the bending stress and Young's modulus are evaluated as functions of moisture content. As the moisture content of the stem increased, shearing stress increased, but bending stress and Young's modulus decreased. The average of bending stress varied between 17.74-26.77 MPa and modulus of elasticity varied between 3.13-3.75 GPa. It proves that the harvesting time and change in physical properties of stem is very important for the response of wheat stem in agricultural activities.

REFERENCES

1. Annoussamy, M., G. Richard, S. Recous and J. Guerif, 2000. Change in mechanical properties of wheat straw due to decomposition and moisture. Appl. Eng. Agric., 16(6): 657-664.
2. Hirai, Y., E. Inoue, K. Mori and K. Hashiguchi, 2002. Analysis of Reaction Forces and Posture of a Bunch of Crop Stalks during Reel Operations of a Combine Harvester. Agricultural Engineering International, the CIGR Ejournal, Manuscript FP 02-002, Vol. IV.

3. Shaw, M.D. and L.G. Tabil, 2007. Compression, Relaxation and Adhesion Properties of Selected Biomass Grinds. Agricultural Engineering International, the CIGR Ejournal, Manuscript FP 07-006, Vol. IX.
4. Yiljep, Y.D. and U.S. Mohammed, 2005. Effect of Knife Velocity on Cutting Energy and Efficiency during Impact Cutting of Sorghum Stalk. Agricultural Engineering International, the CIGR Journal, Manuscript PM, 05-004, Vol. VII.
5. Persson, S., 1987. Mechanics of Cutting Plant Material. ASAE Publications, Michigan.
6. Majumdar, M. and R.K. Dutta, 1982. Impact cutting energy of paddy and wheat by a pendulum type dynamic test. J. of Agric. Eng. Res., 19(4): 258-264.
7. Ince A., S. Uğurluay, E. Güzel and M.T. Özcan, 2005. Bending and shearing characteristics of sunflower stalk residue. Biosyst. Eng., 92(2): 175-181.
8. O'Dogherty, M.J., J.A. Hubert, J. Dyson and C.J. Marshall, 1995. A study of the physical and mechanical properties of wheat straw. J. Agric. Eng. Res., 62: 133-142.
9. Kushwaha, R.L., A.S. Vashnav and G.C. Zoerb, 1983. Shear strength of wheat straw. Can. Agric. Eng., 25(2): 163-166.
10. McRandal, D.M. and P.B. McNulty, 1980. Mechanical and physical properties of grasses. Trans. ASAE, 23(4): 816-821.
11. Prasad, J. and C.B. Gupta, 1975. Mechanical properties of maize stalks as related to harvesting. J. Agric. Eng. Res., 20(1): 79-87.
12. Sakharov, V.V., G.G. Rakmanberdiev and G.G. Guagev, 1984. An investigation into the severing of pre-tensed mulberry stems by a screw-type cutter. Mekhanizatsiya Elekfikikatsiya Sel'Skaogo Khozyaistva, 3: 61-62.
13. Chen, Y., J.L. Gratton and J. Liu, 2004. Power requirements of hemp cutting and conditioning. Biosyst. Eng., 87(4): 417-424.
14. Chattopadhyay, P.S. and K.P. Pandey, 1999. Mechanical properties of sorghum stalk in relation to quasi-static deformation. J. Agric. Eng. Res., 73: 199-206.
15. Anonymous, 2006. ASABE Standards, 52nd Edn. S358.2, 1:1 Measurement-Forages. St. Joseph, MI.
16. Nazari, Galedar, M., A. Jafari, S.S. Mohtasebi, A. Tabatabaeefar, A. Sharifi, M.J. O'Dogherty, S. Rafiee and G. Richard, 2008. Effects of moisture content and level in the crop on the engineering properties of alfalfa stems. Biosyst. Eng., 101: 199-208.
17. Crook, M.J. and A.R. Ennos, 1994. Stem and root characteristics associated with lodging resistance in poor winter wheat cultivars. J. Agric. Sci., 126: 167-174.
18. Khazaei, J., H. Rabani, A. Ebadi and F. Golbabaei, 2002. Determining the shear strength and picking force of pyrethrum flower. AIC Paper No. 02-221, CSAE, Mansonville, Que., Canada.
19. Karadavut, U., S.A. KayiÕ, Ç. Palta and O. Okur, 2008. A growth curve application to compare plant heights and dry weights of some wheat varieties. Am-Euras. J. Agric. Environ. Sci., 3(6): 888-892.