RESEARCH PAPER | Engineering | Volume : 4 | Issue : 9 | September 2014 | ISSN - 2249-555X

Investigation on Mechanical Properties of Sugarcane Stalks for the Development of a Whole Cane Combine Harvester

KEYWORDS: Sugarcane, mechanical properties, combine harvester

Joby Bastian
Regional Agricultural Research Station, Kumarakom, Kerala Agricultural University, Kottayam, Kerala, India.

B. Shridar
Agricultural Machinery Research Centre, AEC&RI, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

ABSTRACT *The mechanical properties of the plant material significantly influence the performance of the different unit operations in combine harvester. Hence, studies of these properties were done prior to the design of sugarcane harvesting system. The mechanical properties of sugarcane stalk viz., bending resistance, cutting resistance, penetration resistance and crushing resistance were studied in the laboratory. It is found that the Young's modulus of the sugarcane stalks as 86MPa, The specific cutting resistance varies between 1764.56 and 957.48kNm^{-2}, penetration resistance ranged from 29.74kNm^{-2} to 56.33kNm^{-2} and the crushing force varied from 0.75kN to 1.53kN.*

INTRODUCTION

Mechanical properties of the sugarcane stalks are to be considered in the development of a sugarcane combine harvester. The design of the major unit operations such as de-topping, base cutting with de-trashing and conveyance are depends upon the above properties.

Mechanical properties of plant stems are important in the design of a harvester as the force and energy requirements are by and large dependent on these properties. Bhaholyotin *et al.* (1988) reported that the hardness, shearing, tension, compression and de-trashing forces play an important role in the design of harvesters.

Chattopadhyay and Pandey (1999) conducted the quasi-static tests using a universal testing machine to determine shear, compressive resistance and bending resistance of forage crops.

Miyabe and Abe (1976) conducted tests with the forces necessary to remove the leaves of cane sugar, using universal testing machine and observed that the traction force to remove the leaves varies with position on the stem and the direction of application.

Miyabe and Abe (1979) did tests to determine the resistance for penetration of the stem, bending, cutting and crushing. They concluded that the penetration resistance varies with node position from top to bottom in the range of 300 to 800kgcm^{-2}. They also concluded that the flexural strength and stiffness increases from top to bottom. The crushing strength (80 to 140kg) increases with the age of the cane and top to bottom.

Miyabe *et al.* (1979) conducted impact tests verifying that the impact energy varies with the location of the nodes, increasing from top to root (2.0 to 4.0kgm). The results show that the inner tissue of the stem is softer and more elastic in the upper parts of the cane.

Paulo *et al.* (2004) studied the mechanical properties of the sugarcane by compression tests using the universal testing machine and for leaves removal test by friction by a special apparatus designed to allow the registration of the normal and traction force. The sugarcane stalk can resist up to 4.9MPa. With a normal pressure of 0.8MPa, which correspond to a friction force of 315N, it is possible to remove the leaves, independent of its location in the sugarcane stalk.

Qingting *et al.* (2006) reported that the flexural modulus and flexural strength of basal stalks of sugarcane were 1172MPa and 46. MPa respectively.

MATERIALS & METHODS

The mechanical properties of sugarcane stalks viz., bending resistance, cutting resistance, penetration resistance and crushing resistance are measured in a Universal Testing Machine (UTM) Unitek-9410.

Bending resistance

The base cutting quality can be accomplished by flexing the canes at the time of cutting and this can be achieved by the use of a knock-down roller positioned forward and above the base-cutter discs. The power requirements of this knock-down roller depend upon the bending properties of the sugarcane. Hence, the bending characteristics of the sugarcane are studied on the UTM by using a specially designed holding device for the sugarcane. The holding device is provided with a socket for holding one end of sugarcane stalk specimen and is held firmly by tightening clamping screws. The socket is fixed to a square pipe which is welded to a 'T' section and can be fitted to the upper vice of the UTM horizontally. The test specimen, held by the jaw at one end, will remain at the cantilever position (Figure 1). Load for bending the specimen is applied at the free end through a clamping mechanism fixed at the lower vice of the UTM. The bending force at different deflections can be recorded from the output of the UTM. The experiment was conducted for different cantilever lengths of 50 and 75mm by changing the clamping position of the of 'T' section on the upper vice. The experiment was conducted using CO-86032 variety of sugarcane and the experiment was repeated for different diameters of the specimen. Young's modulus for each test was calculated using the equation

$$E = \frac{PL^3}{3DI} \qquad \text{----(1)}$$

Where,

Volume : 4 | Issue : 9 | September 2014 | ISSN - 2249-555X

E - Young's modulus,Pa
P - Applied force,N
L - Beam length,m
D - Deflection,m
I - Area moment of inertia

Figure 1. Experimental set up for measuring bending resistance

Cutting resistance
The cutting force required to cut the sugarcane is an important parameter in the design of the base cutter and the de-topper system of the sugarcane combine harvester. Since the development of the machine is aiming at a whole-cane combine harvester the cutting force required at the bottom and top of the matured cane is the influencing factor in the design consideration. Hence the cutting force required at top and bottom is measured in a UTM (Figure 2). The experiment was conducted with the most common variety CO-86032. The cutting forces are measured at the nodes and internodes of the sugarcane where the de-topping and base cutting are to be performed.

Penetration resistance
In small sized sugarcane harvesters, centrifugal cleaning method is adopted rather than compressed air cleaning method (Li *et al.*,2002). The penetration resistance of the cane is considered for the design of the de-trashing system with brushes in the centrifugal cleaning system. The penetration (vertical) force acting on the cane by the bristles of the brushes is to be lesser than the penetration resistance to avoid the damage of the cane by the bristles of the brush.

The penetration resistance of the cane is measured in an UTM using a plunger specially designed for the test. The plunger is fixed on the upper jaw of the UTM and the cane is placed on the lower jaw (Figure 2). The plunger dimensions are based on the size of the bristle (2.5 mm) used in the de-trashing system. The penetration resistance is measured at each internode, numbered from the bottom to top of the sugarcane for the variety CO-86032.

Crushing resistance
The conveyance system of the sugarcane combine harvester consists of counter rotating rollers. The sugarcane was passed between the rollers, which provide the positive drive to the sugarcane. The vertical force exerted by the rollers which acts on the cane should not exceed the crushing resistance of the sugarcane. Hence, the maximum permissible load which can be applied to a cane without damaging the cane is measured by a crushing test. The test is conducted with specially designed gadgets at the upper and lower jaws of the UTM (Figure 2). Since the cane will be under a line contact between the rollers in conveyance, the gadgets are made to simulate the same conditions of contact. The sugarcane of variety CO-86032 was used for the test and the crushing force at each internodes, numbered from the bottom to top of sugarcane are measured in the UTM.

Figure 2. Experimental set up for measuring cutting, penetration and crushing resistance

RESULTS AND DISCUSSION
The mechanical properties of sugarcane stalk viz., bending resistance, cutting resistance, penetration resistance and crushing resistance were studied in the laboratory.

Bending resistance
Bending tests for sugarcane stalk were carried out in the laboratory for studying the stiffness characteristics as cantilever supported beam. Knowing the load and deflection, the modulus of elasticity of the sugarcane stalk was calculated. These properties were used in the design of knock-down roller unit of sugarcane harvester. The Young's modulus of the sugar cane stalks were worked out. It was observed that the Young's modulus of the sugarcane stalks by cantilever beam loading was found as 86MPa.

Cutting resistance
The cutting force required at the top and bottom portion of the sugarcane was measured using an UTM. The cutting forces were measured at the node and at the internode in the top and bottom position. The specific cutting resistance at the bottom and top were 1764.56 and 957. 48kNm^{-2} respectively at the internodes. At the nodes, the specific cutting resistance at the bottom and top were 2147.8 and 1120.45kNm^{-2} respectively. The maximum diameter of the cane during harvest were 40mm and 35mm respectively at bottom and top based on field observations. Hence, taking the maximum specific cutting resistance requirement of 2147.8 and 1120.45kNm^{-2}, the maximum force required for cutting a single cane at bottom was 2.7kN and the same at top was 1.04kN.

Penetration resistance
The internodes were numbered from the bottom to top of the cane and the penetration resistance of the cane was measured at each internode using an UTM. The variations in the penetration resistance with internode number are plotted in the Figure 3. The figure shows that the upper part of the sugarcane has lesser penetration resistance compared to the lower ends. This was because the outer cells of the bottom parts were more thick-walled and lignified due to maturity. The penetration resistance ranged from 29.74 kNm^{-2} to 56.33 kNm^{-2}.

Crushing resistance
The crushing resistance tests were conducted with a specially designed gadget at the upper and lower jaws of the UTM. The crushing forces at each internode were measured and plotted in Figure 3. The crushing force ranged

Volume : 4 | Issue : 9 | September 2014 | ISSN - 2249-555X

from 0.75kN to 1.53kN. The figure showed that the upper part of the sugarcane showed lesser crushing force compared to the lower ends. This was because the outer cells of the bottom parts were more thick-walled and lignified due to maturity.

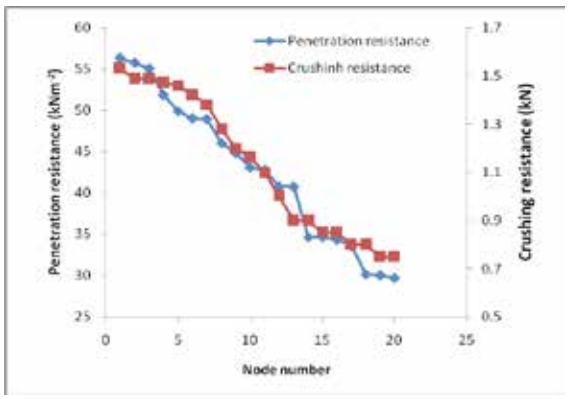

Figure 3. Relationship between node order penetration resistance and crushing resistance

CONCLUSION

The mechanical properties of sugarcane stalk are as follows

1. The The Young's modulus of the sugarcane stalks by cantilever beam loading was found as 86MPa.
2. The specific cutting resistance on the internodes at the bottom and top of the sugarcane stalks were observed as 1764.56 and 957.48kNm^{-2} respectively. At the nodes, the specific cutting resistance at the bottom and top were recorded as 2147.8 and 1120.45kNm^{-2} respectively.
3. The lower parts of the sugarcane has higher penetration resistance when compared to the upper parts and ranged from 29.74kNm^{-2} to 56.33kNm^{-2}.
4. The crushing force of the sugarcane stalks varied from 0.75kN to 1.53kN and the upper part resulted lesser crushing force when compared to the lower part.

REFERENCE Bhaholyotin,B.K.Prasarn,I.Kazumoto and G.Yoshiaki.1988. Study on some physical properties of sugarcane whole stalk harvester design. Kasetsar Journal. 22:88-90. | Chattopadhyay,P.S. and K. P. Pandey.1999. Effect of knife and operational parameters on energy requirement in flail forage harvesting. J. Agric. Eng. Res. 73:3-12. | Li.S.P., Y.M.Meng, E.L.Ma, H.H.Tan and W.X Chen.2002. Research on the working mechanism and virtual design for a brush shape cleaning element of a sugarcane harvester. Journal of Materials Processing Technology. 129:418-422 | Miyabe,Y. and M.Abe. 1976. Fundamental studies on developing a leaf-stripping machine for sugarcane. I -The pulling force needed for leaf detachment. Bulletin of the Faculty of Agriculture, KagoshimaUniversity, Kagoshima. 26: 271-276. | Miyabe,Y. and M.Abe.1979. Fundamental studies on development of a leaf-stripping machine for sugarcane. II - The penetrating, bending, cutting and crushing resistance of a sugarcane stalk. Bulletin of the Faculty of Agriculture, Kagoshima University, Kagoshima. 29:231-243. | Miyabe,Y., M.Abe and S.Kojima.1979. Fundamental studies on the development of a leaf-stripping machine for sugarcane. III - The impact resistance of a sugarcane stalk. Bulletin of the Faculty of Agriculture, Kagoshima University, Kagoshima. 29:245-248. | Paulo,S.G.M., A.B.Oscar and B.P.Natasha.2004. Resistance to compression and leaves removal of sugarcane for mechanical harvesting. Eng. Agríc., Jaboticabal, 24(1) :177-184. | Qingting, L., O.Yinggang and Q.Shangle.2006. Failure forms of sugarcane stalks under torsion, compression and tension and tension load. Transactions of the Chinese society of agricultural engineering. 22(6):201-204. |