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Ultimate Strength Characteristics of Switchgrass Stem Cross-Sections at Representative Processing Conditions

Manlu Yu
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Manlu Yu entitled "Ultimate Strength Characteristics of Switchgrass Stem Cross-Sections at Representative Processing Conditions." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

Alvin R. Womac, Major Professor

We have read this thesis and recommend its acceptance:

Michael J. Buschermohle, Paul D. Ayers

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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Ultimate Strength Characteristics of Switchgrass Stem Cross-Sections at Representative Processing Conditions

A Thesis
Submitted for the
Master of Science Degree
The University of Tennessee, Knoxville

Manlu Yu
August 2004

To:
My parents, Chunyu Yu and Chanjuan Cai
For their devotion, encouragement, guidance, and support through my life

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Abstract

Switchgrass stem cross-sections were failed with ultimate shearing stresses that were one-fifth the magnitude of ultimate tensile stresses, thereby indicating that shear-dominant size reduction equipment would be much more efficient than tensile-dominant size reduction processes. Individual tensile strength measures ranged from 28 to 205 MPa and shear strength ranged from 6.9 to 38 MPa for all test conditions. Tests were conducted throughout a cropping season to obtain a range of switchgrass properties representative of those available for typical biomass processing. Representative processing conditions were organized and statistically tested based on switchgrass variety, maturity, elapsed time after harvest, moisture content, stem diameter, and stem thickness. Significant differences were detected among tensile and among shear strength measures for switchgrass lowland varieties of Alamo and Kanlow. Mean tensile strength increased as mean moisture content decreased from about 60 to 10 % wet basis, and tensile strength increased two-fold with a corresponding increase in elapsed time after harvest ranging from 2 to 386 h. This indicated that tensile-dominant size reduction should be conducted early in the harvest process and at a high moisture content to minimize energy consumption for grinding. Mean shear strength was relatively unaffected by moisture content and elapsed time after harvest.

Data analyses also provided indicators of consistency and validity of the test method. For example, desiccation of stem samples for tensile and shear tests occurred at the same statistical rate even though a slightly offset testing schedule was a necessary strategy to accommodate coincident measures. Mean stem moisture was statistically consistent throughout the study. Diameter and thickness of stems slightly decreased as

time after harvest increased, possibly due to a stem shrinkage phenomena associated with desiccation. Switchgrass stem diameter and thickness were directly proportional to moisture content, with Pearson correlation coefficients of 0.24 ($P = 0.0$) and 0.30 ($P = 0.0$), respectively. Test cross section widths of samples were consistent among varieties and maturity class, thereby indicating uniform sample preparation throughout the experiment.

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I. Introduction

Energy consumption increases steadily as the world's population grows and living standards rise. Currently, fossil fuel sources meet the industrial and domestic energy demands. Environmental issues and depletion of fossil fuel resources demand development of alternative energy sources. Biomass as an energy source may offer an environment-friendly alternative to petroleum based fuels.

Biomass is a renewable energy resource since production may replace material stocks (Kitani, 2004). Energy from the biomass, based on application and economics may generate power and heat, and may have the potential to improve global and regional environments through reduced emissions. Moreover, using biomass as a fuel source helps to reduce greenhouse gas emissions that arise from combustion of fossil fuels (Mani et al., 2002).

Agricultural crop residues are a significant renewable biomass resource. Crop residues from 27.8 million ha of grain corn, 19.7 million ha of wheat, and 1.7 million ha of barley were harvested by American farmers in 2001. Potential biomass supply data for the United States was assembled by Oak Ridge National Laboratory (ORNL). Some biomass residues are already used as raw materials for particleboard and fiberboard, or as household and industrial fuels. The high volume and low density characteristics of agricultural-produced biomass are a significant impediment to using biomass feedstock for many processes, including bioenergy production (ORNL, 2003).

Biomass size reduction is an important step in processing raw biomass for energy production and biomass feedstock. Mechanical size reduction may reduce the time and energy to convert the biomass into useful products. In addition, size reduction is also an important operation in densification and handling an otherwise unwieldy crop (Lopo, 2002). Low density characteristics of biomass increase transportation costs and often make it difficult to feed the material into processing equipment.

Switchgrass (*Panicum virgatum*) is a variety of grass that is native to the Americas and its spread extends from Canada to South America. Switchgrass was considered as the most promising herbaceous energy crop in the U.S.A. (Sanderson et al., 1996; Christian et al., 2002). It stands out because of its adaptation to a wide range of soil and climate conditions, low fertilization and weed control requirements, and high crop yield (10-12 t/ha/annum) (Goel et al., 1998). Some varieties of switchgrass can grow as tall as 3 m, with most of the growth occurring in the hottest and driest parts of the growing season. Increasing interest in harvesting and commercial use of switchgrass has prompted the need for basic engineering data on switchgrass properties.

Late-flowering Alamo and Kanlow switchgrass varieties were selected as the input material in this study based on their higher yield, broader adaptability, and long period of availability (Reynolds et al., 2001; Sanderson et al., 1996). Little is known about switchgrass mechanical properties that would be applicable to size reduction and other physical processes.

In general, a universal testing machine measures load-displacement characteristics and may be used to determine the tensile and shear strengths of biological materials. Some previous studies reported tensile and shear strengths of wheat straw (Burmistrova et al., 1963; Limpiti, 1980; Kushwaha et al., 1983; O'Dogherty, 1989; Usrey et al., 1992; O'Dogherty et al., 1995), and alfalfa (Halyk and Hurlbut, 1968; Greenberg et al., 1989) at different moisture contents. More studies have focused on materials of brittle nature (Austin, 1971). Unlike homogeneous sample cross-sections, switchgrass is nonhomogenous and may have varying thickness and diameter. Others noted that complex shapes and variation in diameter of fibrous biomaterials lead to difficulty in determining physical properties of materials and in performing fundamental calculations based on stem dimentions (Prince et al., 1968). Unavailability of the basic mechanical properties data published for Alamo and Kanlow switchgrass varieties motivated this study.

By determining the effects of various factors affecting the tensile and shear strengths, an optimal method of switchgrass size reduction can be designed. It is believed that results of this study could be applied to bioenergy production using switchgrass by aiding optimal size reduction strategies. This information also serves as basic engineering design data for better biomass size reduction equipment and processes.

The overall objective of this technical study was to determine the ultimate strength characteristics of selected cross sections of switchgrass stems available under a range of conditions representative of occurring during a processing timeframe. Specific objectives were as follows:

1. Determine fundamental tensile and shear strength characteristics of selected cross sections of switchgrass stems.
2. Evaluate the effects of switchgrass conditions on tensile and shear strengths. Specific conditions include switchgrass variety, maturity, elapsed time after harvest, moisture content, stem diameter and stem thickness.
3. Establish correlations between observed specific conditions, as listed in 2.

II. Review of Literature

Burmistrova et al. (1963) investigated the physico-mechanical properties of agricultural plants to be applied to agricultural machine design. Plant size, weight, volume and strength indices of various plant parts subjected to the action of different machine working parts were obtained. Mechanical strength of plant parts was determined in order to provide the experimental basis for the machine designer's work.

Halyk and Hurlbut (1968) computed ultimate tensile strength of alfalfa stems on the basis of maximum tensile load carried by a test piece taken from different sections of a single plant. Test results showed considerable variation in the ultimate tensile strength of test specimens. Both the ultimate tensile strength and ultimate shear strength were found to be inversely proportional to moisture content and directly proportional to dry matter density.

Prince et al. (1968) provided engineering properties of corn stalks, including tensile, compressive, and shear strengths, and bending characteristics. They stated that the mechanical properties of biological materials were not always possible to determine as precisely as metals. The difficulty of making exact physical measurements may lead to errors in determining stress, strain and modulus of elasticity.

Austin (1971) described the theory behind size reduction of homogenrous brittle materials. The resulting distribution of particle sizes was discussed. The author concentrated on differential equations describing the breakage of particles, and applied them to finding the amount of grinding effectiveness completed in some small period of time Δt. The rate of breakage of material in mathematical equations and steady state of continuous grinding were described.

Ige and Finner (1976) developed a mathematical model based on the energy requirements to shear whole alfalfa stems and corn stalks. Their objective was to minimize shearing energy. They concluded that increased moisture content reduced shearing energy.

Limpiti et al. (1980) investigated the effects of moisture content and stage of maturity on mechanical properties of two varieties of wheat straw. Moisture content and stage of maturity had significant effects on the energy required to cut and break straw.

Kushwaha et al. (1983) modified a soil shear apparatus to determine the shear strength of wheat straw at different moisture levels and shearing speeds. They reported that the minimum values of shear strength (7 to 10 MPa) occurred at stem moisture content from 8 to 10% wet basis (w.b.). At lower moisture levels straw was found to be more brittle and thus easier to break.

Greenberg et al. (1989) studied the tensile behavior of ryegrass (*Lolium perenne L.*). The conclusion was that stiffness, toughness, and strength of grass increased as strain rate increased, though ductility was inversely proportional to strain rate. Also, the brittle behavior increased with increased strain rate. Increased brittle tensile behavior was generally associated with reduced toughness values.

Usrey et al. (1992) studied the properties of rice straw focusing on tensile strength, shear strength, and pressure-density relationships during compression. The ultimate tensile strength of individual rice straws ranged from 87 to 168 N for stems with cross-sectional area of 0.05892 to 0.14234 cm^2 for an average stem moisture content of

58.to 79% w.b. From these values, the ultimate tensile strength ranged from 14.8 to 17.7 MPa. They also found a linear relationship between ultimate tensile strength and moisture content of alfalfa, the same as rice straw.

Jenkins (1989) discussed the physical properties of biomass. These included moisture content, density, morphological characteristics, mechanical properties, electronic properties, and thermal properties. Associated with each of these were the effects on handling and processing, and the interaction among properties. He stated that shear and tensile strength properties were important in determining the force and energy requirements of biomass processing such as particle size reduction.

O'Dogherty (1989) studied the high density compression of straw to produce briquettes for fuel or other purposes. Information on the physical properties of straw, the compression characteristics, the formation of briquettes and the theoretical considerations of compression were provided.

O'Dogherty et al. (1995) studied the physical properties of tensile and shear strength of cutting stems between wheat straw nodes. Tensile strength ranged from 22.7 to 31.2 MPa and shear strength ranged from 5.14 to 6.55 MPa for the third stem internode from the plant ear, and Young's modulus was between 5.70 and 6.39 GPa as moisture content ranged from 8.2 to 22.0%. They found that plant maturity significantly affected shear strength.

Sanderson et al. (1996) demonstrated that switchgrass was well suited as a herbaceous energy crop. Switchgrass has the important attributes of high yield, efficient use of water and nutrients, low agrochemical inputs, and improved soil and water conservation. A technique for regenerating switchgrass plants via tissue culture was demonstrated.

Goel et al. (1998) studied the potential pulp fibre source for future pulp and paper production. Increased wood costs led to increased interest in switchgrass as a wood replacement. Fibre characteristics, pulpability, physical properties, and strength properties were discussed in this report.

Annoussamy et al. (2000) examined shearing and bending stress properties of wheat straw left on a soil surface. They attributed an increased Young's modulus and maximum bending stress of the internode to its increased proportion of hemicellulose. The decomposition properties of wheat were studied focusing on the relationship between the ability to shear and bend the wheat straw and the wheat straw moisture and decomposition.

Reynolds et al. (2001) compared the biomass yields of switchgrass at two locations in Tennessee and under two harvest systems (one-cut: cut once near the end of October, and two-cut: cut in early summer and near the end of October). Early-flowering and late-flowering types of switchgrass were included under two management systems.

Christian et al. (2002) studied seven varieties of switchgrass (*Panicum virgatum L.*) and one panic grass (*Panicum amarum* A.S. Hitchc. & Chase) under maritime temperature conditions. Yield was measured after flowering and when stems were dead in the winter for four to five years. Mineral concentration in the stems was higher at flowering than in dead stems.

Lopo (2002) examined particle reduction processes by comparing roll, horizontal, and vertical grinding methods. Energy consumption of grinding and related factors were studied. Vertical hammer devices had lower energy consumption, less moisture loss, reduced grinding shrink, narrower particle size, and fewer fines.

Mani et al. (2002) studied energy crops including straw, corn stover, and switchgrass with a hammermill. The purpose was for densification to aid storage and transportation. Physical characteristics of the resulting particles were studied including the distribution of particle size, moisture content, geometric mean diameter, and bulk densities. The experiment found that increased hammermill screen size resulted in reduced energy requirements.

Conger (2003) developed biotechnological systems to improve switchgrass. One thousand regenerated plants were established in the field during the first year. Alamo (lowland type) was found to be much more amenable to regeneration much than Cave-in-Rock (upland type).

Kitani (2004) reviewed biomass resources including the principles of biomass utilization, biomass energy, biomass environmental considerations, and biomass systems. Biomass energy was the main concern in this chapter. Liquid, gas and solid fuel from biomass was discussed, as well as the energy demand and the potential of biomass energy.

The overall literature review showed that the shear and tensile strength properties were important in determining the force and energy requirements of biomass processing such as particle size reduction. O'Dogherty (1989) indicated a range of ultimate tensile strength of 9 to 32 MPa for wheat straw (var. Fenman), and shear strength values ranged from 5.39 to 6.98 MPa for five varieties of winter wheat and was 8.53 MPa for spring wheat (var. Alexander), at moisture contents ranging from 10 to 15% w.b. Moreover, O'Dogherty et al. (1995) determined that tensile strength was in the range 22.7 to 31.2 MPa and shear strength ranged from 5.14 to 6.55 MPa for the third stem internode from the wheat straw plant ear as moisture content ranged from 8 to 22% w.b. Burmistrova et al. (1963) reported the ultimate tensile strength values ranging from 128 to 399 MPa for several wheat varieties. But these were based on stem wall areas of solid material, which are a factor of 5 to 10 times smaller than the geometrical wall area. Limpiti (1980) found tensile strength values of 32.5 to 37.8 MPa for moisture contents ranging from 10 to 65% w.b. of wheat straw (var. Sirus and Maris Butler). Usery et al. (1992) showed ultimate tensile strength ranged from 14.8 to 17.8 MPa for rice straw as moisture content ranged from 58 to 79% w.b. Kushwaha et al. (1983) reported shear strengths of wheat straw ranged from 7 to 22 MPa with moisture content ranging from 5 to 30% w.b. Minimum values of shear strength (7 to 10 MPa) occurred for stem moisture contents between 8 to 10% w.b. The plant maturity had some effect on shear strength (O'Dogherty et al., 1995). Knowledge of the physical properties of any biomass, which is being subjected to a mechanical process, is valuable in interpreting its behavior, and strength values available in these published articles were based on active-growth plant. No information was found for switchgrass properties of tensile and shear strengths

III. Methods and Materials

Switchgrass variety selection

Six switchgrass varieties named Cave-in Rock, Alamo, Kanlow, Shelter, NC 1-16, and NC 2-16 were previously established in May 1992 at the Plant Sciences Unit, Knoxville Experiment Station, The University of Tennessee (Figure 3.1). Based on higher yield, broader adaptability, and long period of availability, the late-flowering varieties Alamo and Kanlow were selected as our experimental organism for the tensile and shearing tests of individual stems. Previous studies (Reynolds et al. 2001; Conger 2003) showed that the switchgrass cultivars Alamo and Kanlow were both lowland ecotypes, and were the highest yielding switchgrass cultivars in Tennessee and nation wide. Also, the lowland cultivars Alamo and Kanlow were much easier to regenerate than upland cultivars. Alamo cultivars had higher biomass yield and broader adaptability than other cultivars tested. Early-flowering cultivars named Cave-in-Rock and Shelter did not utilize as much of the growing season, and did not yield as much as the late-flowering varieties Alamo and Kanlow in a one-cut system of harvesting. A one-cut harvest system was typically implemented near the end of October or early November.

Switchgrass field harvest

A comprehensive study was performed over a two and one-half month period during the switchgrass growing season. The two varieties of switchgrass, Alamo and Kanlow were manually harvested biweekly on Tuesday mornings. Alamo was harvested

Figure 3.1. Switchgrass plot at Experiment Station in Knoxville, Tennessee

from two replicate plots beginning the first week of July 2003, and Kanlow was harvested from two replicate plots beginning the second week of July 2003. This staggered sample schedule facilitated the required time to harvest and prepare samples.

Information regarding the plot and variety were marked on poles to minimize errors in selecting the proper switchgrass variety (Figure 3.2). Individual switchgrass stems were harvested with manual pruning shears and were cut between the ground level and the first node (Figure 3.3). Eight samples per variety (four samples per plot), sampling time, and tensile/shear strength test were collected in the field (Figure 3.4), placed in a plastic box, and transported to the laboratory within 30 minutes of stem cutting.

Switchgrass maturity stages were arbitrarily classified based on the elapsed time from fresh regrowth. Days were arbitrarily numbered from zero when fresh regrowth was first observed in the spring. Classes 1, 2, 3, 4, and 5 corresponded with 96, 110, 124, 138, 152 days for Alamo and with 103, 117, 131, 145, 159 days for Kanlow.

Instrument description

A universal testing machine (MTS Alliance RT/30, MTS Systems Corporation, Eden Prairie, Minnesota) was used in the experiment (Figure 3.5 and Figure 3.6). A 1000-N capacity load cell (D64827) was mounted to the crosshead. TestWorks 4.05 of MTS Systems Corporation’s latest testing software was installed to control the universal testing machine and data acquisition. This software had various method templates available. One of the commonly used templates was General Testing Package. This package provided a “starting point” to configure test methods to conform to the testing

Figure 3.2. Switchgrass Alamo at Experiment Station in Knoxville, Tennessee

Figure 3.3. Cutting position in the field using pruning shear

Figure 3.4 Switchgrass sample collection from field

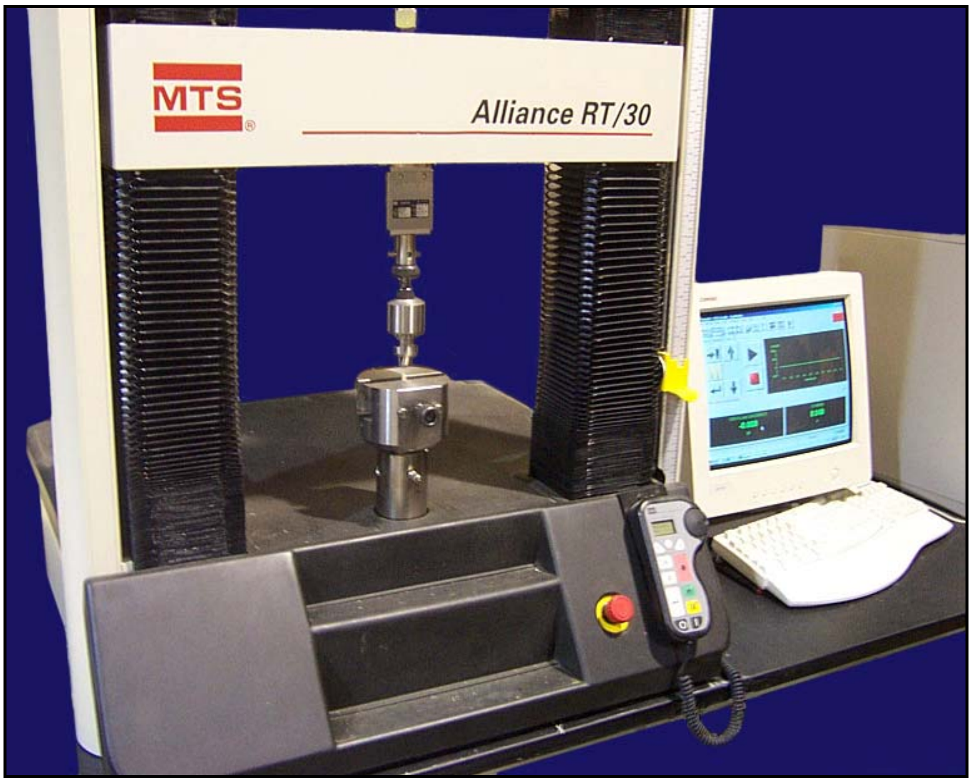

Figure 3.5. Universal testing machine (mounted with tools for tensile test)

Figure 3.6. Universal testing machine (mounted with tools for shear test)

needs. This package had 4 specific testing categories (MTS tensile, MTS compression, MTS flex, and MTS peel-tear). MTS Tensile Method template was used for the tensile and shearing tests since the instrument applied tensile forces to both sets of sample mounting tools.

Calibration before each test was performed automatically via computer software by choosing the calibration option. Load-displacement measurements were observed through the computer system. Pound (lb) was used as loading force unit with an accuracy 0.001 lb for this instrument, and then converted to Newton (N) when doing stress/strength calculations. Specimen displacement was the extension of switchgrass when loading. The unit of displacement was inch (in), and later was converted to meter (m) for analysis. The grips for holding the test specimen between the fixed frame and moveable crosshead were self-aligning by way of a universal connection joint. The specimen was freely moved into alignment as soon as any load was applied so that the long axis of the test specimen coincided with the direction of the applied force through the centerline of the grip assembly.

Experimentation and calculation

In the laboratory, the harvested stems were stored as separate lots on wire shelves dedicated to each variety and harvest date, and were exposed to the ambient room condition with consistent temperature (~ 24˚C) and humidity (~ 65%). Pre-test studies confirmed that this storage environment was preferred over storage in a laboratory without environment control.

Leaves of switchgrass stems were separated first and then the internodes were cut from samples. Internode length ranged from 170 to 230 mm, with an average length of 200 mm. The 2nd internodes were used for tensile or shear test and the corresponding 3rd internodes were used for moisture content determination (Figure 3.7).

In order to obtain a high number of data and to adhere to similar test conditions (Table 3.1), the tensile test was conducted at 2, 26, 74, 146, 242 and 386 hours after switchgrass harvest. The shear test was conducted at 6, 30, 78, 150, 248 and 390 hours after switchgrass harvest. These times were selected to accommodate the staggered weekly harvest of each variety. Longest elapsed time was determined based on the switchgrass reaching equilibrium moisture content with environmental conditions.

<u>Tensile testing</u>

Tensile stress acts on a plane normal to the applied load. Measurement of ultimate tensile strength for the complete cross section of switchgrass stems was difficult because the specimens failed at the clamps before failing at the desired internode cross section. Evidently the clamp introduced stress concentrations to cause failure at the point of contact between the clamp and switchgrass.

Teeth in the crosshead clamping chuck crushed the switchgrass before failing the undisturbed cross-section. Because the outside skin of switchgrass was smooth, and the required breakage force was more than the holding force provided by the gripping devices, slippage problems were observed at the end of a specimen for complete switchgrass cross sections. Twisting of the switchgrass while gripping with two drill

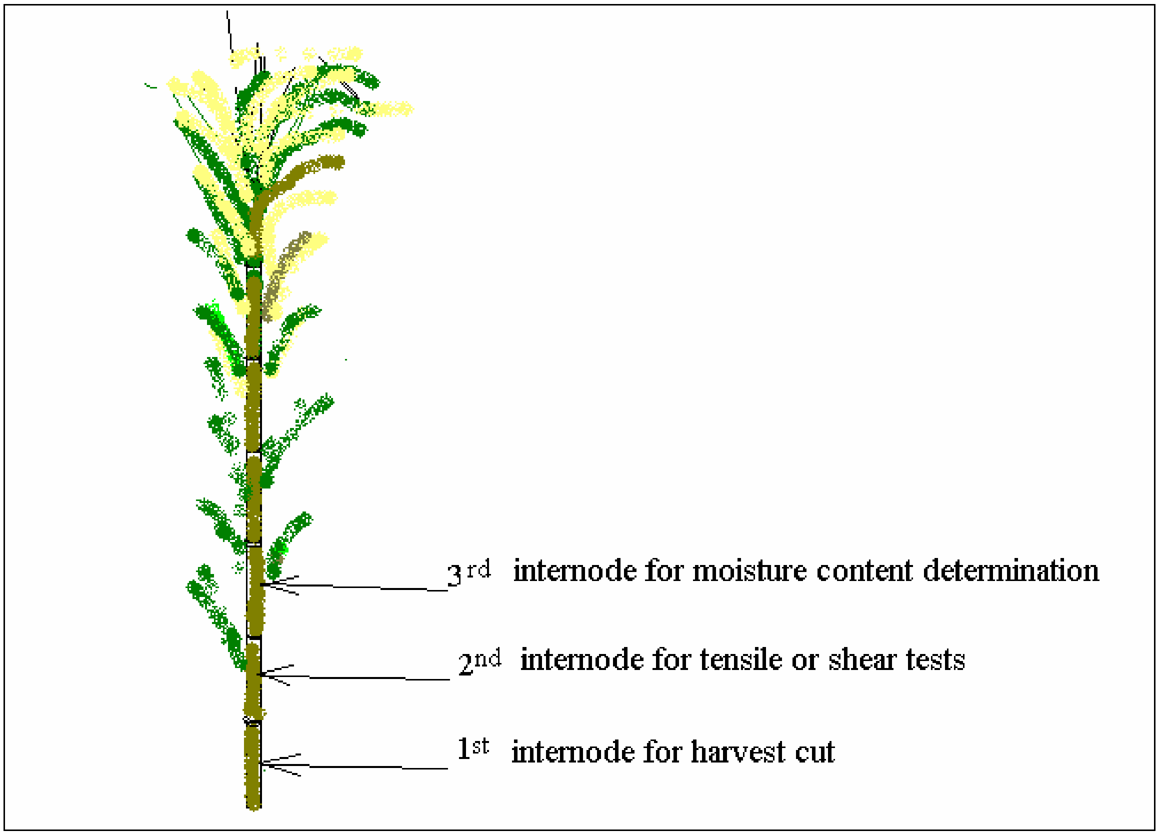

Figure 3.7 Depiction of switchgrass sample

Table 3.1 Example of the weekly harvest and test schedule

Sun	Mon	Tue	Wed	Thu	Fri	Sat
---		A^1	a^1		a^1	---
---	a^1	K^1	k^1		a^1/ k^1	---
---	k^1	A^2	a^2	a^1	k^1/ a^2	---
---	a^2	K^2	k^2	k^1	a^2/ k^2	---
---	k^2	A^3	a^3	a^2	k^2/ a^3	---
---	a^3	K^3	k^3	k^2	a^3/ k^3	---

A or a – Alamo variety; K or k – Kanlow variety
A^n – harvest & test day; a^n – next test for samples from nth harvest
Example: A^1 – harvest & first test day; a^1 – next test from 1st harvest

chucks also caused pre-breakage because of inadvertent longitudinal motion introduced by tightening the final chunk. Hence, the most difficult problem in tension testing of biological material was finding a proper gripping device, which would hold the ends of the specimen tight without overstress, slippage, and twist.

In order to avoid these problems mentioned above during the tensile test, a three-jaw drill chuck was chosen for the top gripper. A flat gripper with two wavy pattern grip pieces was chosen in the bottom to avoid twist and shortening introduced by a second chuck (Figure 3.8). Also to rectify slippage problems, sand paper was used to roughen the ends of switchgrass skin to increase friction.

From the preliminary experimented runs, it was found that the whole switchgrass samples couldn't be successfully tested for tensile stress with the chuck and flat gripper due to insufficient gripping. Hence, the following method of switchgrass sample preparation for tensile testing was developed:

In this method, the 2nd internode of the hollow switchgrass stem was split into two halves along the longitudinal direction. The ends were filled with uncut small-diameter switchgrass stems so that the ends resembled a solid cylinder (Figure 3.9). Cyanoacrylate glue (Super Glue Corporation ® of Pacer Technology, Rancho Cucamonga, California) was used to adhere the uncut stems. The uncut stem filling prevented the switchgrass from being crushed when the ends were inserted and gripped in the chuck. Even though it was possible to have a failure in the middle of an unfilled portion of the sample, it was very difficult to control and predict the place of failure. Hence, notching was done at the middle section. A circular hole-puncher (Figure 3.10) was used to cut two small notches on opposing sides of the sample so as to leave a neck having a width of around 1.65 mm

Figure 3.8. Tensile test with specimen held by clamps

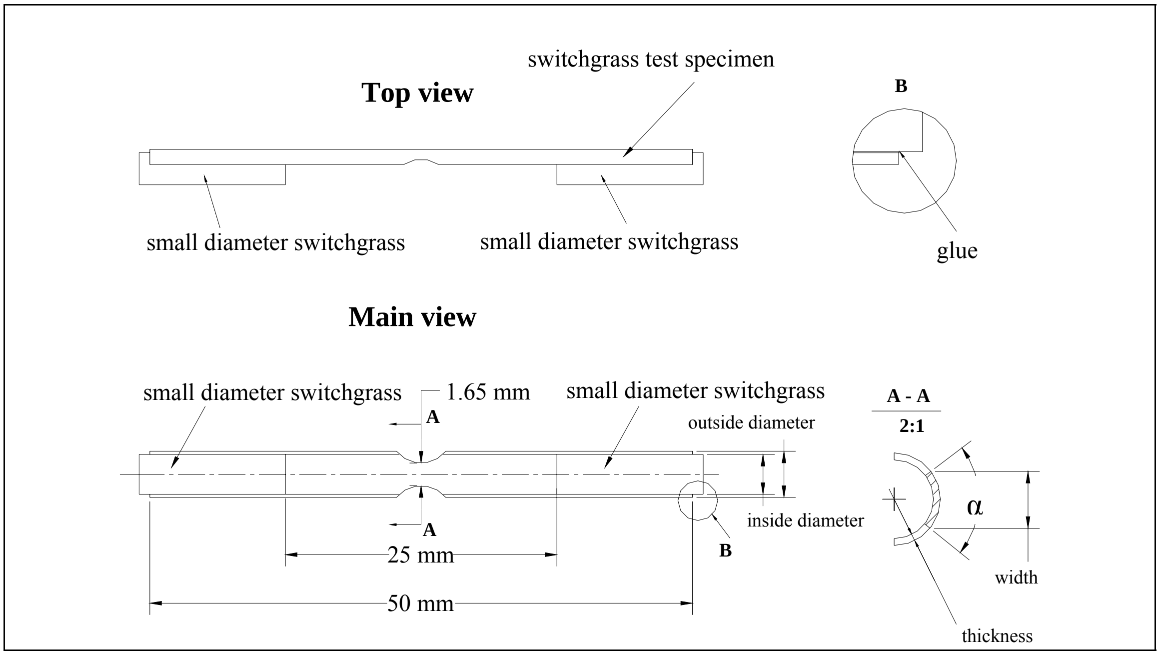

Figure 3.9 Diagram for switchgrass specimen preparation in tensile test

Figure 3.10 A circular hole puncher for cutting switchgrass sample notch

(Figure 3.9). Because of this notching, less breakage force was expected due to less cross-section area. This helped to ensure a controlled failure in the neck region. Sand papers strips were wrapped around the sample ends to avoid the possibility of producing stress concentration and to improve grip. The middle uncovered portion of the sample length was kept at 25 mm for each test. Final overall lengths were trued to a length of 50 mm.

When the sample was mounted and loaded in the universal testing machine, a force displacement curve was generated by the software package with the maximum tensile stress at breakage highlighted. Figure 3.11 shows an example of tensile force versus displacement curve acquired by the MTS computer. Initial load observed in the force-displacement curve was caused while securing the sample in the chuck. This initial load was not zeroed in order to obtain the sample failure load directly. The flat portion of the force-displacement curve was due to the initial adjustment of the sample between the grippers before the actual loading occurred. This flat portion might have been avoided by applying a pre-stress during clamping of the samples, though the absolute exact reason for the flat portion was not fully determined but large relative to whole curve. A crosshead speed of 0.1 inch (0.254 mm) per minute was selected, which was the minimum available speed of the machine. The lowest crosshead speed was selected to improve data collection of the failure event. It should be noted that the selected crosshead speed, and any that were available, was well below anticipated strain rates of biomass grinders. Results are for quasistatic loading.

The switchgrass geometric physical properties such as diameter, thickness, and width of individual stalk specimen were measured with a digital micrometer with a

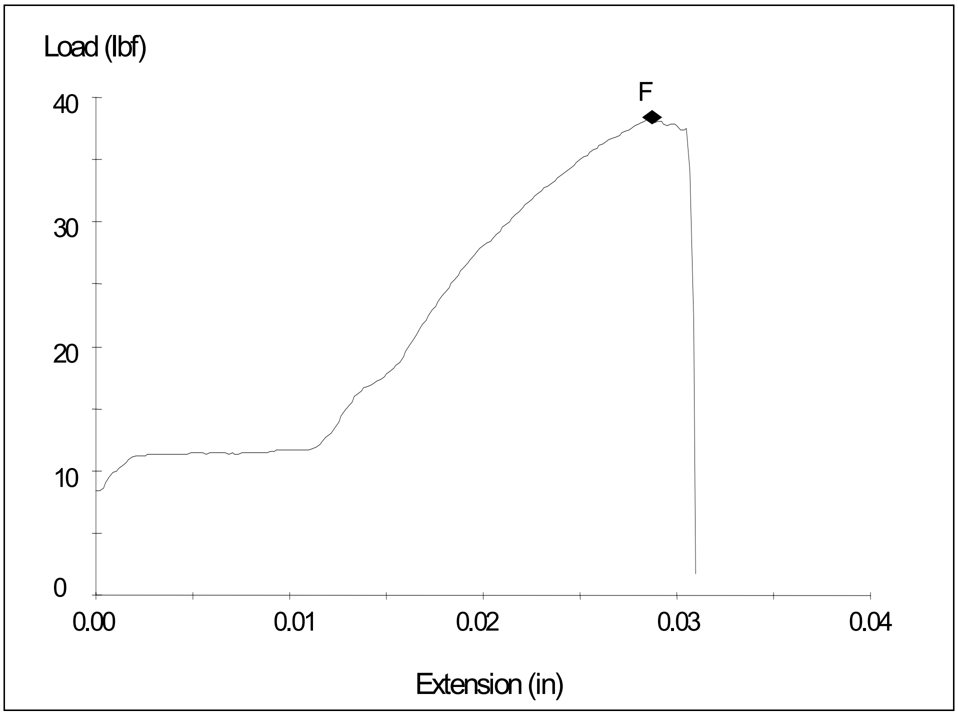

Figure 3.11 The data curve of a tensile load on the ordinate (Y) axis versus extension on the abscissa (X) axis

maximum four decimal resolution (0.000 in). For a tensile test, diameter was twice measured at the specimen middle before splitting into half. Two measures of diameter were averaged. Thickness was measured at the two ends of the specimen after the sample was split into half, and the average thickness was calculated. Width was measured at exactly mid-point of the notch (Figure 3.9). The ultimate tensile strength of the switchgrass stem was computed as a stress from the maximum breaking force and stem cross-sectional area at the notch.

The tensile failure stress (or ultimate tensile stress), σ, of the specimen was calculated from the expression:

$$\sigma = \frac{F_t}{A} \times 10^{-6} \qquad (1)$$

where,

σ = tension stress at failure, MPa

F_t = tension force at failure, N

A = area of failure cross-section at notch of the specimen, m^2

The cross section of neck part for the specimen was assumed as rectangular though it was slightly curved, and was evaluated as:

$$A = W \times T \qquad (2)$$

where,

A = estimated cross section area of sample of failure at notch, m^2

W = width of the cross-section area of sample at failure, m

T = average thickness of the switchgrass specimen, m

Potential errors caused by this assumption of a rectangular cross section were due to the slight curvature of the cross section. Potential variation was calculated by the following formulas:

$$\alpha = 2\arcsin\frac{W}{D} \tag{3}$$

$$A_{max1} = (\frac{D_{max}^{2} - d_{max}^{2}}{4}) \times \pi \times \frac{\alpha_{max}}{360} \tag{4}$$

$$A_{max2} = T_{max} \times W_{max} \tag{5}$$

$$Varience1 = \frac{A_{max1} - A_{max2}}{A_{max2}} \times 100 \tag{6}$$

$$A_{min1} = (\frac{D_{min}^{2} - d_{min}^{2}}{4}) \times \pi \times \frac{\alpha_{min}}{360} \tag{7}$$

$$A_{min2} = T \times W_{min} \tag{8}$$

$$Varience2 = \frac{A_{min1} - A_{min2}}{A_{min2}} \times 100 \tag{9}$$

where,

A_{max1} = maximum area of the curved area, m^2

A_{max2} = maximum area of the rectangular area, m^2

A_{min1} = minimum area of the curved area, m^2

A_{min2} = minimum area of the rectangular area, m^2

α = angle corresponding to the curved area, degrees

α_{max} = maximum angle corresponding to the curved area, degrees

α_{min} = minimum angle corresponding to the curved area, degrees

W = width of the notch where the failure occurred, m

D = outside switchgrass diameter of the sample stem, m

d = inside switchgrass diameter of the sample stem, m

T = average thickness of the switchgrass specimen, m

Variance1 = area variation among the maximum rectangular area and the maximum curved area, %

Variance2 = area variation among the minimum rectangular area and the minimum curved area, %

The minimum and maximum bold values in Table 3.2 are obtained by sorting all test specimens for outside diameter, thickness, and width respectively. The other corresponding variables are obtained from the information of that specific switchgrass specimen. The area variation of assuming the maximum curved area as maximum rectangular area is presented as variation1, and the area variation of assuming the minimum curved area as minimum rectangular area is presented as variation2. Some of the area variations are large; it might be due to the switchgrass physical properties which are based on for calculation. Because switchgrass do not have exactly circular stem, the uncertain parameter of switchgrass caused some large variations.

The tensile strength of the specific curved area was considered as the same as the strength of complete cross section area for the sample. But tensile force of the complete cross section calculated based on the force of the curved area was less than the real tensile force of the complete cross section area, because the complete cross section area of the sample is larger and has more possibility of weak linkage.

Table 3.2 Potential variations between actual curved cross sectional area and assumed rectangular area based on diameter, thickness or width

	Outside Diameter (m)	Thickness (m)	width (m)	Inside Diameter (m)	Alpha (°)	Curved Area (m^2)	Rectangular Area (m^2)	Var (%)
Min	**0.002426**	0.000419	0.00146	0.00100	74.04	7.8785E-07	6.1210E-07	28.71
Max	**0.005207**	0.000787	0.00220	0.00221	49.91	2.4208E-06	1.7300E-06	39.93
Min	0.002438	**0.000356**	0.00071	0.00104	33.91	3.5970E-07	2.5290E-07	42.22
Max	0.004839	**0.001003**	0.00203	0.00192	49.66	2.1383E-06	2.0387E-06	4.88
Min	0.003708	0.000699	**0.00074**	0.00150	22.91	5.7425E-07	5.1452E-07	11.61
Max	0.004077	0.000914	**0.00295**	0.00158	92.56	2.8513E-06	2.6942E-06	5.83

Shear Testing

Shearing stress acts on a plane parallel to the applied load. A double-shear box was developed (Figure 3.12) to apply a shear stress. The shear box was made from steel stock and consisted of an outside steel box into which a solid inside box slid freely in a close sliding fit (like a tenon and mortise). A series of holes with diameters of 1/8, 3/16, 1/4, 3/8, 1/2, 1/2 in (3.175, 4.7625, 6.35, 9.525, 12.7, and 12.7 mm) were drilled through both boxes after alignment. The holes accommodated switchgrass specimens of differing diameter that were inserted. One of the 1/2 in (12.7 mm) diameter holes was used as an alignment hole, by pushing a steel pin though it prior to loading the sample.

Shear force was applied to the switchgrass specimens by mounting the shear box in the universal testing machine operated similar to tensile test. The 2nd internode of specimen was chosen for the shear test and inserted into the closest diameter hole of the shear box. Care was taken so that the sample length was centrally placed through the selected shear box hole for the test. The outside-box was loaded at a crosshead speed of 0.1 in (0.254 mm) per minute. The shear box offered no significant frictional resistance when operated without a sample (Figure 3.13). Figure 3.14 shows an example of shear force versus displacement curve generated through the MTS software. The force-displacement profile was obtained up to the failure of the specimen. The initial flat profile along extension axis was indication of clearance between the switchgrass sample and the hole in the shear box. It should be noted that the samples failed at the planes corresponding to the gaps between the inside and outside boxes of shear box assembly. Failure area was twice the cross sectional area of the switchgrass stem.

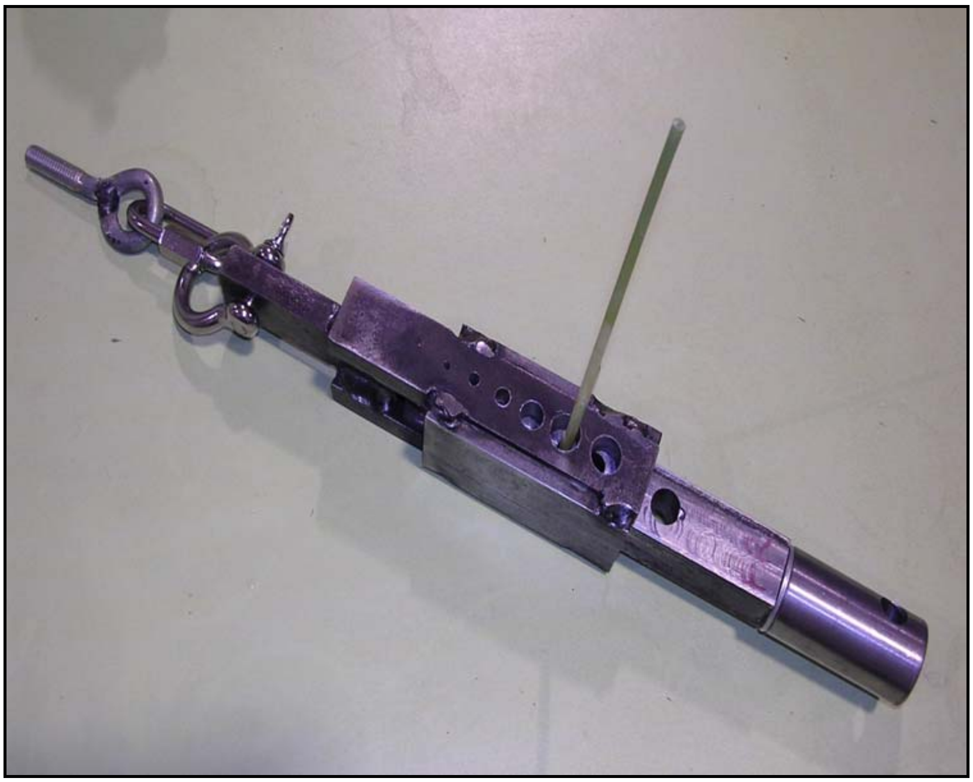

Figure 3.12 Shear box for applying shear stress to switchgrass stems

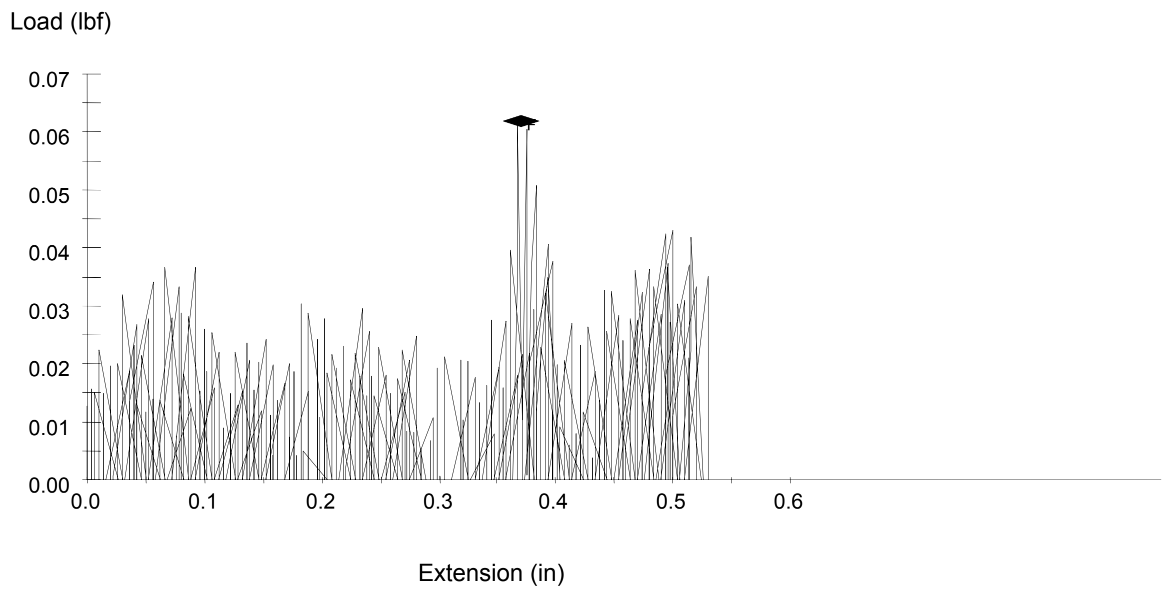

Figure 3.13 Initial loads when running the shear test without switchgrass sample

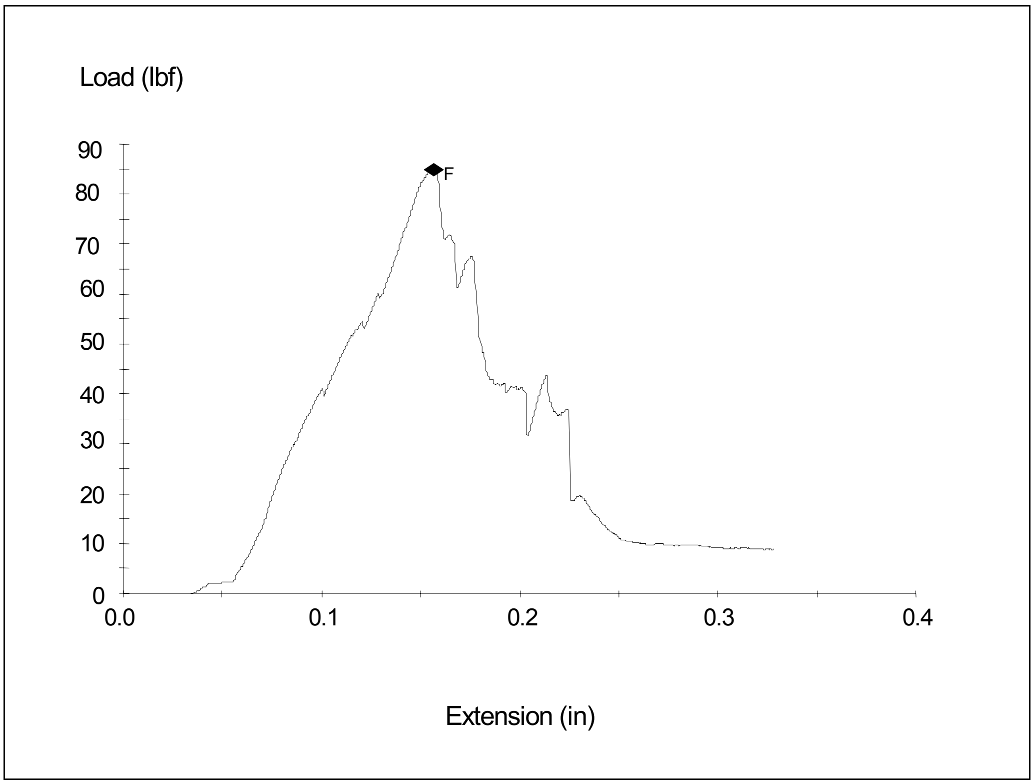

Figure 3.14 The data curve of a shear load on the ordinate (Y) axis versus extension on the abscission (X) axis

The ultimate shear strength of the switchgrass stem was computed from the maximum shearing loads that were applied to the switchgrass stem. After the hollow switchgrass stem had been sheared, the inside and outside diameters were measured near the point of failure as broken stem pieces were removed from the shear device. The ultimate shear strength was determined by calculating the area enclosed within the outside and inside diameters of the stem. Noting that the shearing test was a double shear, the shear failure stress (or ultimate shear stress), τ, of the specimen was calculated from the expression:

$$\tau = \frac{F_s}{2A} \times 10^{-6} \qquad (10)$$

where,

τ = shear stress at failure, MPa

F_s = shear force at failure, N

A = area of each (one) failure cross-section, m^2

Area of failure cross-section was calculated using the following equation:

$$A = \frac{D^2 - d^2}{4} \pi \qquad (11)$$

where,

D = outside switchgrass diameter, m^2

d = inside switchgrass diameter, m^2

Moisture content determination

ASAE Standard S358.2 (ASAE Standards, 2003) for forages (air oven at 103°C for 24 hours) was used to determine moisture content of all the specimens from the 3rd internodes. Initial weight of individual specimen was measured using a sensitive digital balance (Figure 3.15) with a resolution of 0.001g prior to drying in an air oven. All the prepared samples of stalk section were loaded in the preheated oven and their final dry weights were determined after 24 h immediately after removal from the oven. From the initial and final weights, the moisture contents of samples were determined using wet basis. Switchgrass was typically harvested at about 60% moisture content wet basis (w.b.) moisture and laboratory dried to about 10% moisture content (w.b.) after the last test period (386 h).

Data analysis

Instrument readings of failure force and switchgrass cross sectional areas were used to compute failure strength (stress) as indicated in a previous section. These data were entered into a spreadsheet to perform the actual calculations. The spreadsheet file is printed in Appendix.

Statistical software (SAS OnlineDoc® 9.1, 2003) was used for statistical analysis. The dependent variables were tensile strength and shear strength, and the independent variables were switchgrass variety, moisture content, and elapsed time after harvest (hours-after-harvest), switchgrass maturity class, and geometric dimensions (diameter, thickness, and width).

Figure 3.15 Digital balance for switchgrass weight measurement

Data were subjected to a one-way classification analysis of variance (ANOVA) with a 5 percent level of significance. Tukey–Kramer mean separation analysis was conducted to compare all the possible pairwise combinations among the means. Pearson correlations between combinations of the dependent and continuous independent variables were examined using PROC CORR (SAS Institute Inc., SAS Cary, N.C.). Select correlation results were identified for presentation either based on statistical significance or the importance of the correlations to representative processing conditions. Representative processing conditions were changes in test factors that would be associated with normal desiccation, aging, and characteristics occurring with a biological crop during different phases of mechanical harvest, process, and storage. Finally, various graphs were presented as an aide to identify or support trends or lack thereof.

IV. Results

Tensile strength analysis

The mean ultimate tensile stress (mean tensile strength) of Alamo was 97.8 MPa with a standard deviation of 32.5 MPa, and the individual measures ranged from 27.7 to 205 MPa for all test conditions. Likewise, the mean tensile strength of Kanlow was 89.7 MPa with a standard deviation of 31.8 MPa and individual measures ranged from 9.3 to 213 MPa for all test conditions. Since a wide range of switchgrass conditions were tested, tensile strength had a wide range. Relations between tensile strength and test conditions are explored in a later section.

The ANOVA showed a significant difference of mean tensile strengths for the two switchgrass varieties. Kanlow had a smaller tensile strength value than Alamo. P-statistics of this test showed a significant difference (P = 0.0091). Mean separation results showed two different statistical levels (A and B) which further proved tensile strength values of these two varieties were significantly different (Table 4.1).

Measured tensile strength was compared with some of the published tensile strength values of biomass (Table 4.2). O'Dogherty (1989) indicated a range of ultimate tensile strength of 9 to 32 MPa for wheat straw (var. Fenman) with moisture content ranging from 10 to 14% w.b. Limpiti (1980) found the tensile strength values of 32.5 to 37.8 MPa for moisture contents ranging from 10 to 65% w.b. of wheat straw (var. Sirus and Maris Butler). Another report by O'Dogherty et al. (1995) determined that tensile strength was in the range 22.7 to 31.2 MPa for the third stem internode from the wheat straw plant ear as moisture content ranged from 8 to 22% w.b. Usery et al. (1992) found

Table 4.1 Mean tensile and shear strengths of individual switchgrass stems for two switchgrass varieties.

	Switchgrass Variety	
	Alamo	Kanlow
Mean Ultimate Tensile Strength (MPa) (Std.Dev.)	97.8 A[1]a[2] (32.5)	89.7 A b (31.8)
Mean Ultimate Shear Strength (MPa) (Std.Dev.)	20.5 B a (6.7)	17.9 B b (5.0)

[1]Uppercase alpha letters indicate column-wise mean separation
[2]Lowercase alpha letters indicate row-wise mean separation

Table 4.2 Switchgrass tensile strength

Switchgrass Variety		Range of Ultimate Tensile Strength (MPa)	Range of Moisture Content (% w.b.)
Alamo		27.7-205	10-60
Kanlow		9.3-213	10-60
Comparison with published biomass value			
Source	Biomass Varity	Range of Ultimate Tensile Strength (MPa)	Range of Moisture Content (% w.b.)
O'Dogherty (1989)	Wheat Straw	9-32	10-14
Limpiti (1980)	Wheat Straw	32.5-37.8	10-65
O'Dogherty et al. (1995)	Wheat Straw	22.7-31.2	8-22
Usery et al. (1992)	Rice Straw	14.8-17.8	58-79

ultimate tensile strength for rice straw ranged from 87 to 168 N for effective areas of 0.05892 to 0.14234 cm^2 which corresponded ultimate tensile strength ranged from 14.8 to 17.8 MPa. Moisture content ranged from 58 to 79% w.b. Burmistrova et al. (1963) reported the ultimate tensile strength values ranging from 128 to 399 MPa for several wheat varieties. But these were based on stem wall areas of solid material, which are a factor of 5 to 10 times smaller than the geometrical wall area.

Both Alamo and Kanlow had wider range of tensile strength than published values. All of the published strength values were based on the active-growth grass, but the present data associated the elapsed time after harvest as switchgrass dried in the lab. This might cause a difference between the data herein and published data.

Shear strength analysis

The mean ultimate shear stress (mean shear strength) of Alamo was 20.5 MPa with a standard deviation 6.7 MPa. Shear strength varied from 7.03 to 39.9 MPa for all test conditions. Likewise, the mean shear strength of Kanlow was 17.9 MPa with a standard deviation 5.0 MPa. Shear strength ranged from 6.9 to 38 MPa for all test conditions. Relations between shear strength and test condition are examined in a later section.

The ANOVA showed a significant difference of mean shear strengths for the two switchgrass varieties. Kanlow had a smaller shear strength value than Alamo. P-statistics of this test shows a significant difference ($P = 0.0091$). Mean separation result showed two different levels (A and B), which further proved shear strength values of these two varieties were significantly different (Table 4.1).

Shear strength of other biological materials were also reported by previous researchers (Table 4.3). O'Dogherty (1989) studied wheat straw and reported shear strength values ranged from 5.39 to 6.98 MPa for five varieties of winter wheat and 8.53 MPa for spring wheat (var. Alexander), for moisture contents ranging from 10 to 15% w.b. Moreover, O'Dogherty et al. (1995) reported that the shear strength ranged from 5.14 to 6.55 MPa for wheat straw (var. Mercia) at the third internode from plant ear as moisture content in the range 8 to 22% w.b. Kushwaha et al. (1983) reported shear strengths of wheat straw ranged from 7 to 22 MPa with moisture content ranging from 5 to 30% w.b. Minimum values of shear strength (7 to 10 MPa) occurred for stem moisture contents between 8 to 10% w.b. All results were based on tests of active-growth samples.

Most published articles focused on shear strength studied at low moisture content. But the data herein covered a wide moisture content range that may result in differences with published values. Even though our mean shear strength value had wider range than published mean shear strength values, at very low moisture content, shear strength data generally matched the same order of magnitude of published data.

Comparison of tensile strength versus shear strength

Mean ultimate tensile strengths versus mean ultimate shear strengths required to fail individual stems are shown in Table 4.1.

The ANOVA showed a significant difference between mean tensile strengths versus mean shear strengths for both switchgrass varieties. Mean shear strengths were lower than mean tensile strengths. P-statistics of both tests showed a significant difference ($P < 0.0001$) for both varieties. Mean separation results further showed the

Table 4.3 Switchgrass shear strength

Switchgrass Variety		Range of Ultimate Shear Strength (MPa)	Range of Moisture Content (% w.b.)
Alamo		7.0-39.9	10-60
Kanlow		6.9-38	10-60
Comparison with published biomass value			
Source	Biomass Varity	Range of Ultimate Shear Strength (MPa)	Range of Moisture Content (% w.b.)
O'Dogherty (1989)	Wheat Straw	5.39-6.98	10-15
Kushwaha et al. (1983)	Wheat Straw	7-22	5-30
		7-8	8-10
O'Dogherty et al. (1995)	Wheat Straw	5.14-6.55	8-22

significant difference between tensile strength and shear strength with different levels of A and B for Alamo, as well as Kanlow.

The ratio of tensile to shear strength for Alamo was 4.77. Kanlow had a tensile to shear strength ratio of 5.00. These ratios for the two varieties were similar. The only information about the tensile to shear ratio reported was 4.34 (26.5 MPa / 6.1 MPa) for the third stem internode from the ear of wheat straw at moisture content ranged from 8.2 to 22.0% (O'Dogherty et al 1995). Thus, switchgrass tensile to shear ratios were similar to previous tests.

The observed shear strengths were one-fifth of the tensile strength values to fail individual stems of the both switchgrass varieties. Therefore a shear dominant size reduction operation will be much more energy efficient than tensile-based operation.

Based on the results, it will be beneficial for the biomass engaging machine elements to apply more cutting and shearing action and less tensile forces.

Effect of moisture content on tensile and shear strengths

Mean tensile strength increased as mean moisture content decreased for both Alamo and Kanlow switchgrass varieties. Mean shear strength did not show a clear trend with the change in mean moisture content.

For tensile tests, the Pearson correlation coefficients (Table 4.4) between moisture content and tensile strength for both Alamo and Kanlow varieties were negative values, which meant the tensile strength increased while the moisture content decreased. P-statistics indicated that tensile strength and moisture content were significantly correlated ($P < 0.01$). For shear tests, the Pearson correlation coefficients between moisture content and shear strength for both Alamo and Kanlow did not show a significant correlation ($P > 0.5$). Though the variables showed a slightly positive relationship, they were not significantly correlated.

Figure 4.1 shows the decreasing trend of tensile strength with increases in moisture content. Figure 4.2 shows the mean tensile strength decrease as the moisture content increase for both switchgrass varieties throughout the period after harvest in all maturity class. Moisture varied due to natural desiccation as the time elapsed after harvest. Letter TS of legend code TS1a in Figure 4.2 represents tensile strength, the numeral in the third position represents maturity class (1, 2, 3, 4, or 5), and the letter in the fourth position represents switchgrass variety (a for Alamo, k for Kanlow).

Mean tensile strength increased about 50% as mean moisture content decreased

Table 4.4 Pearson correlation coefficients between tensile and shear strengths versus moisture content

Variable	Variety	Count	Correlation Coeff	Prob
Tensile Strength vs. Moisture Content	Alamo	215	-0.4835	0.0000
	Kanlow	208	-0.4392	0.0000
Shear Strength vs. Moisture Content	Alamo	216	0.0416	0.5432
	Kanlow	219	0.0438	0.5195

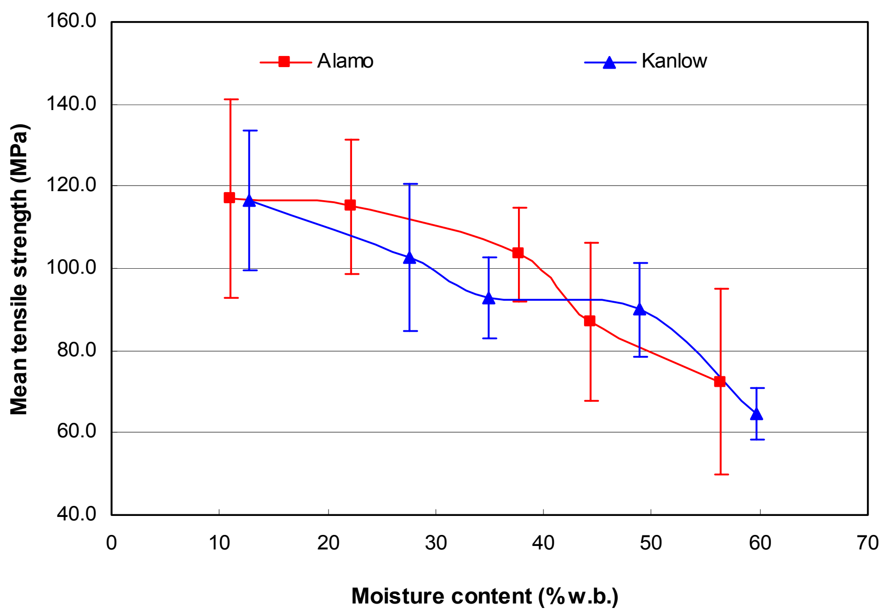

Figure 4.1 Mean tensile strength versus corresponding mean moisture content for two switchgrass varieties. Error bars on data points indicate plus/minus one standard deviation

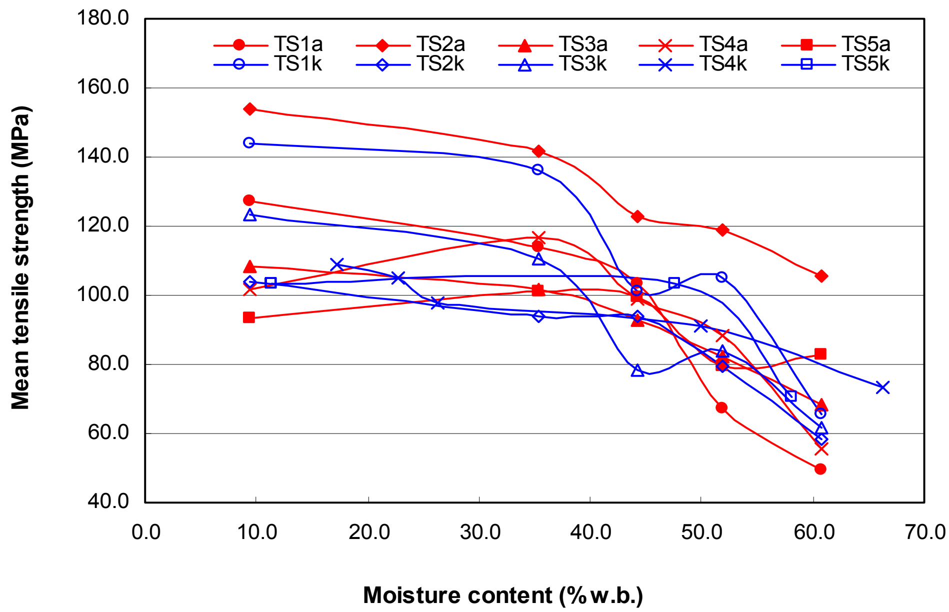

Figure 4.2 Mean tensile strength versus corresponding mean moisture content for two switchgrass varieties at five maturity classes

about 50%. The corresponding mean tensile force increased about 30% and associated cross sectional area decreased about 30%. Thus, the reduction in cross section area due to desiccation accounted for some of the increase in mean tensile strength, but not entirely.

Correlation between shear strength and moisture content did not show a clear trend (Figures 4.3 and 4.4), and had a smaller correlation coefficient value 0.04 for both the varieties. This may be interpreted that shear strength was relatively insensitive to moisture content. Letter SS of legend code SSa1 in Figure 4.4 represents shear strength, the numeral in the third position represents maturity class (1, 2, 3, 4, or 5), and the letter in the forth position represents variety (a for Alamo, k for Kanlow).

Previous research (Halyk and Hurlbut, 1968) found that both shear and tensile

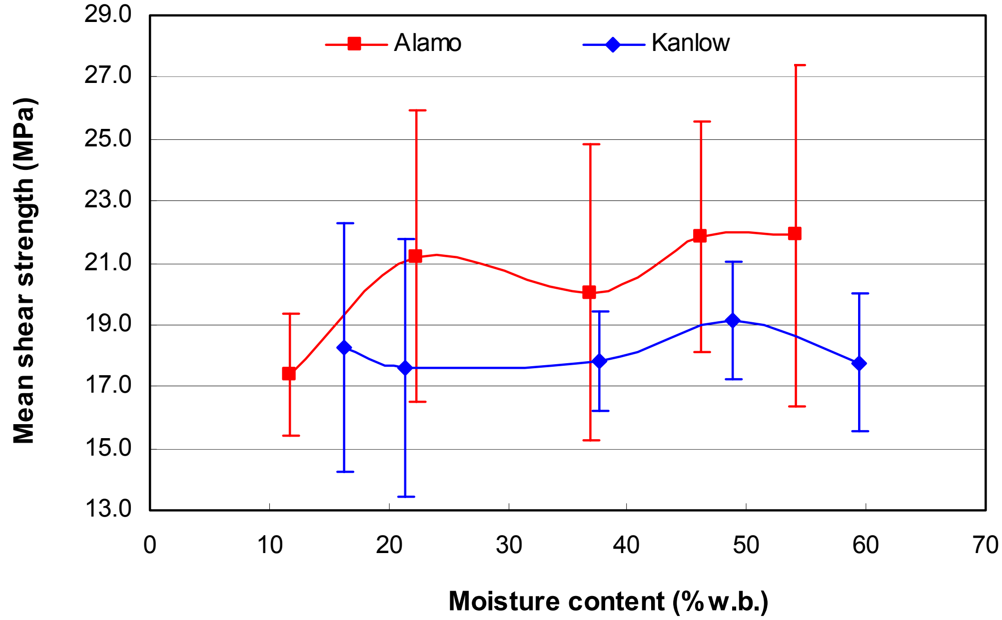

Figure 4.3 Shear strength variations with moisture content for two switchgrass varieties. Error bars on data points indicate plus/minus one standard deviation

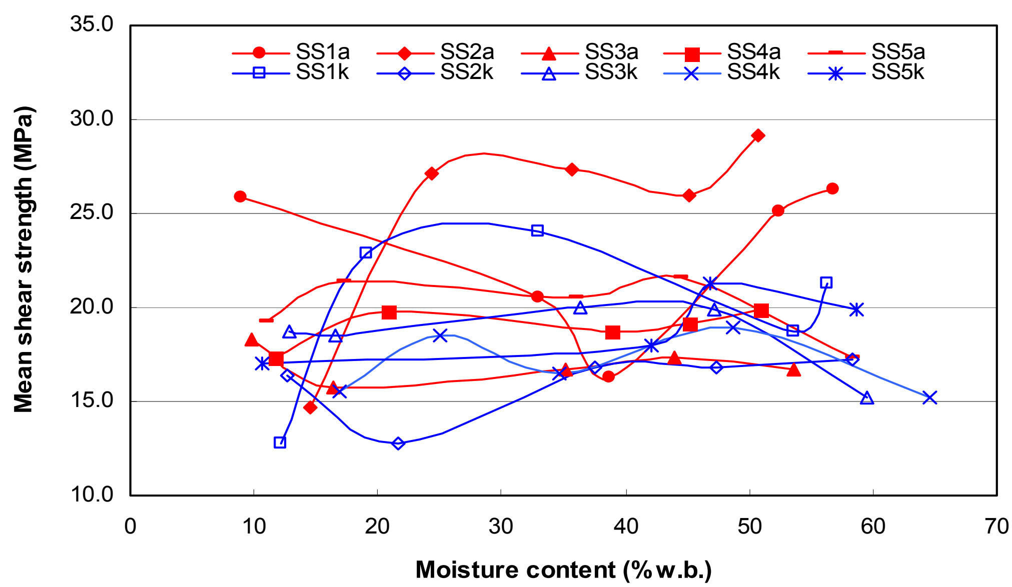

Figure 4.4 Shear strength versus corresponding moisture content for two switchgrass varieties at five maturity classes

strengths of alfalfa were inversely proportional to moisture content. Also both strengths decreased with increasing moisture content for ryegrass (Greenberg et al., 1989). Annoussamy et al. (2000) observed that shear strength increased as moisture decreased for wheat straw. Ige and Finner (1976) provided a similar result for corn stalk and alfalfa. They conclude that increased moisture content reduced the shearing energy of the forage.

A few other studies found an opposite trend between strength of a biological material and moisture content. Kushwaha et al. (1983) stated that it was easer to shear at lower moisture levels for wheat straw. In their study, minimum shear strength occurred at moisture contents ranging from 8-10%. O'Dogherty et al. (1995) reported that shear strength was significantly smaller for 8 and 10% w.b. than for increased moisture content levels which may be due to the driest straw being more brittle.

Results of tensile strength versus moisture content for Alamo and Kanlow showed the similar trend as the published values for alfalfa, wheat straw, and corn stalk. Tensile strength increased as moisture content decreased.

But for shear strength, the results were different as published. Shear results did not show a clear trend, possibly because of small changes in shear strength with varying moisture content. Factors that are less sensitive to changes in another factor would likely lead to increased difficulty in identifying clear trends.

Effect of time after harvest on tensile and shear strengths

Time after harvest significantly influenced tensile strength but not shear strength. This may have been partially due to a relation between time after harvest and moisture content, which is explored in a later section. Mean tensile strength increased with increasing time after harvest. Tensile strength versus hours after harvest for Alamo and Kanlow showed a significant difference with both $P < 0.0001$. Results (Table 4.5) showed nearly a two-fold increase in tensile strength as elapsed time increased from 2 to 386 h, which corresponded to a decrease in moisture content from about 60-12% w.b. Mean tensile strength showed a 77% increase from 2 h after harvest to 386 h after harvest for Alamo variety. For Kanlow, the tensile stress showed an increase of 117%. Even though a significant difference was also observed for shear strength versus hours after harvest with P values of 0.0088 for Alamo and 0.0189 for Kanlow, the letters in the group didn't change so much. Therefore, shear failure was almost insensitive to elapsed time after harvest for both Alamo and Kanlow varieties. Mean shear strength versus elapsed time after harvest did not show a clear trend during the decreases in moisture content.

Table 4.6 shows the correlations between tensile strength versus time after harvest, and shear strength versus time after harvest for Alamo and Kanlow switchgrass varieties. This correlation analysis confirmed that tensile strength increased as hours-after-harvest increased since those coefficients were positive. The correlation coefficient between tensile strength and time after harvest was about 0.5 ($P = 0.0000$). By contrast, shear strength was almost insensitive to time after harvest. A less clear trend was observed in the shear strength as a function of time after harvest (Table 4.5). The correlation between the shear strength and time after harvest (Table 4.6) showed the correlation coefficient of -0.0729 ($P = 0.1282$). These results confirmed that the mean shear strength remained relatively unchanged with the time after harvest when the drying of material takes place.

Table 4.5 Effect of hours after harvest on tensile and shear strengths of Alamo and Kanlow

Hours After Harvest (Tensile)	Mean Ultimate Tensile Strength (MPa) (Std. Dev.)		Hours After Harvest (Shear)	Mean Ultimate Shear Strength (MPa) (Std. Dev.)	
	Alamo	Kanlow		Alamo	Kanlow
2	72.2 B[1] (±27.1)	66.3 D (±15.3)	6	21.2 AB (±7.6)	17.7 AB (±4.2)
26	81.1 B (±18.1)	92.4 C (±19.5)	30	21.5 AB (±6.6)	19.3 A (±4.8)
74	103.0 A (±23.3)	72.1 D (±36.5)	78	20.0 AB (±6.8)	17.7 AB (±3.6)
146	113.9 A (±31.0)	102.0 BC (±20.5)	150	21.1 AB (±6.9)	17.7 AB (±6.4)
242	112.8 A (±34.0)	120.5 AB (±28.3)	248	17.3 B (±4.3)	19.2 A (±5.9)
386	127.3 A (±39.3)	143.7 A (±28.7)	390	25.8 A (±6.4)	12.8 B (±2.9)

[1] Uppercase alpha letters indicate column-wise mean separation

Table 4.6 Pearson correlation coefficients of tensile strength and shear strength versus time after harvest for Alamo and Kanlow

Variable	Variety	Count	Correlation Coff	Prob
Tensile strength vs. Hours after harvest	Alamo	215	0.477	0.0000
	Kanlow	208	0.578	0.0000
	Combined Alamo and Kanlow	423	0.527	0.0000
Shear strength vs. Hours after harvest	Alamo	216	-0.057	0.4044
	Kanlow	221	-0.1246	0.0644
	Combined Alamo and Kanlow	437	-0.0729	0.1282

Tensile strengths versus time after harvest of switchgrass for Alamo and Kanlow are shown in Figure 4.5, when the switchgrass moisture contents decreased from 60 to 10%. Both curves showed the increase in tensile strength with increase in the time after harvest. Curves for the shear strength versus time after harvest of switchgrass for Alamo and Kanlow are shown in Figure 4.6, and these curves did not show a clear trend between shear strength and hours after harvest for the two switchgrass varieties. Based on the tensile strength results observation, it is more energy efficient to reduce particle size soon after harvest, if tensile failure dominates the size reduction device.

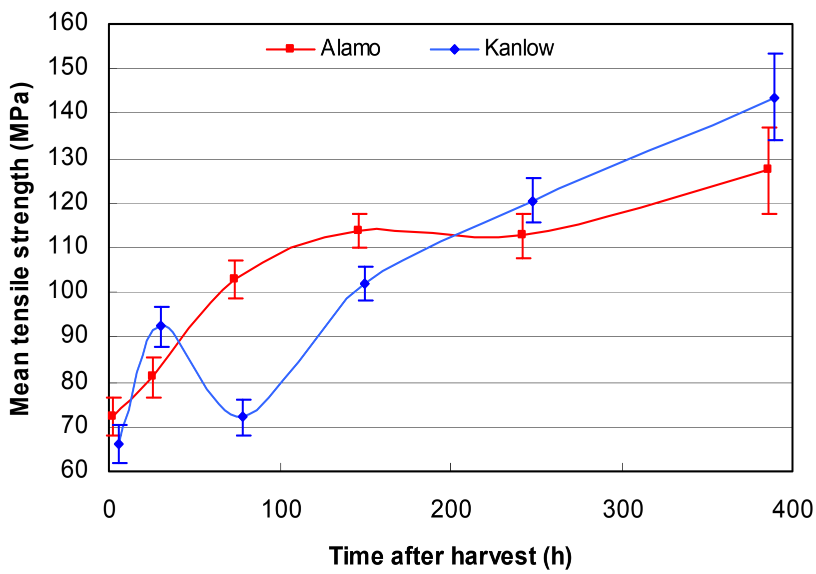

Figure 4.5 Tensile strength versus elapsed time after harvest. Error bars on data points indicate plus/minus one standard deviation.

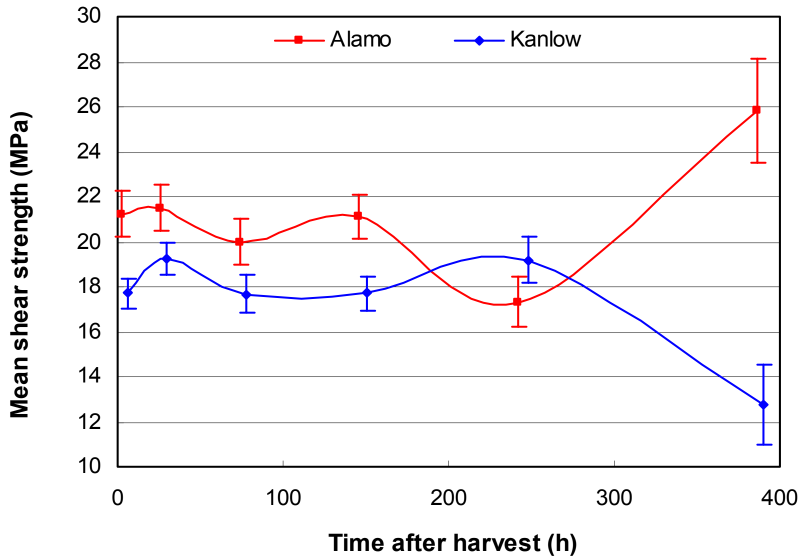

Figure 4.6 Shear strength versus elapsed time after harvest. Error bars on data points indicate plus/minus one standard deviation.

Effect of maturity on tensile and shear strengths

Tensile strength slightly decreased with an increase in maturity class (Table 4.7). The overall correlation coefficient between these two variables was -0.16, even though the magnitude of this value was rather small, the statistical significance was strong (P = 0.0009). The individual correlation coefficients for the Alamo and Kanlow varieties were both –0.14 (P ≈ 0.03).

Correlation between mean shear strength and maturity class was prominent only for Alamo variety. Shear strength decreased as the maturity increased. The correlation coefficient value was –0.23 (P = 0.0006) for Alamo. The overall correlation coefficient between shear strength and maturity class value for all varieties was –0.19 and was significant (P = 0.0000). However, the results indicated that the Alamo variety was more

Table 4.7 Pearson correlation of tensile and shear strength versus maturity class for Alamo and Kanlow switchgrass varieties

Variable	Variety	Count	Correlation Coeff	Prob
Tensile Strength vs. Maturity class	Alamo	215	-0.1429	0.0363
	Kanlow	208	-0.1471	0.0339
	Combined Alamo and Kanlow	423	-0.1608	0.0009
Shear Strength vs. Maturity	Alamo	216	-0.2305	0.0006
	Kanlow	219	-0.0655	0.3323
	Combined Alamo and Kanlow	437	-0.1935	0.0000

sensitive to maturity class than the Kanlow variety (P = 0.33) when considering shear strength.

Results showed that Kanlow variety could be harvested at any time and maturity would not significantly affect shear strength (Table 4.8 and Figure 4.8).

Effect of maturity class on tensile and shear strength values of individual stems of Alamo and Kanlow switchgrass varieties are given in Table 4.8. Variation of tensile and shear strength values with maturity class are also shown in Figures 4.7 and 4.8 respectively. No clear trend was observed between tensile/shear strength versus maturity class.

Effect of thickness and diameter on tensile and shear strengths

Tensile strength had inverse relations with thickness and diameter (Table 4.9). Tensile strength versus thickness correlation coefficient value (-0.5370) was found to be more than twice the correlation coefficient value of tensile strength versus diameter (-0.2006). The better correlation of thickness with tensile strength was probably due to the fact that stem cross-section area was directly calculated using thickness rather than the diameter.

Moisture content versus time after harvest

The overall correlation coefficient between moisture content and time after harvest class for both switchgrass varieties was about –0.86 (P = 0.0000) for tensile and

Table 4.8 Effect of maturity class on tensile and shear strength means of tests involving individual stems of Alamo and Kanlow switchgrass varieties

Maturity Class	Mean Ultimate Tensile Strength (MPa) (Std. Dev)		Mean Ultimate Shear Strength (MPa) (Std. Dev)	
	Alamo	Kanlow	Alamo	Kanlow
1	92.7 B[1] (38.0)	103.9 A (35.01)	22.8 AB (7.6)	19.9 A (5.9)
2	129.8 A (33.2)	87.2 BC (23.4)	24.5 A (8.2)	15.5 C (4.6)
3	90.9 B (28.1)	88.7 ABC (28.3)	17.0 C (4.3)	18.5 AB (5.6)
4	93.8 B (28.4)	72.0 C (39.0)	19.1 BC (5.9)	19.2 AB (4.4)
5	91.3 B (21.1)	94.2 AB (20.5)	20.0 BC (4.8)	17.0 BC (3.7)

[1] Uppercase alpha letters indicate column-wise mean separation

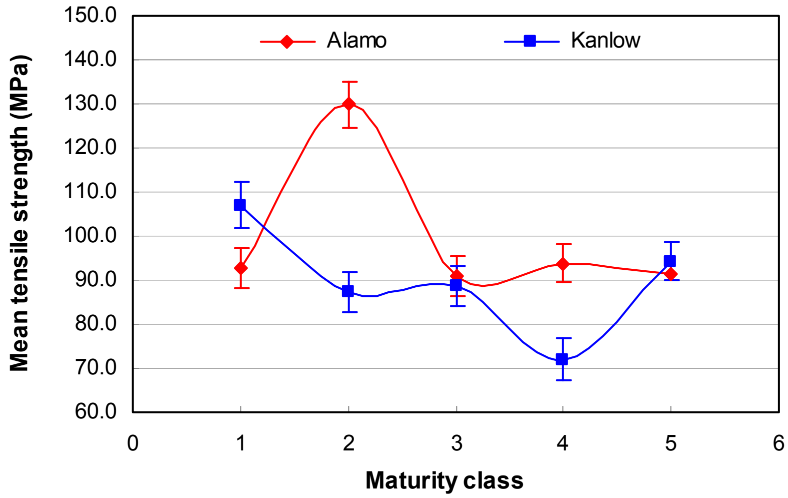

Figure 4.7 Tensile strength variations with maturity class for two switchgrass varieties. Error bars on data points indicate plus/minus one standard deviation

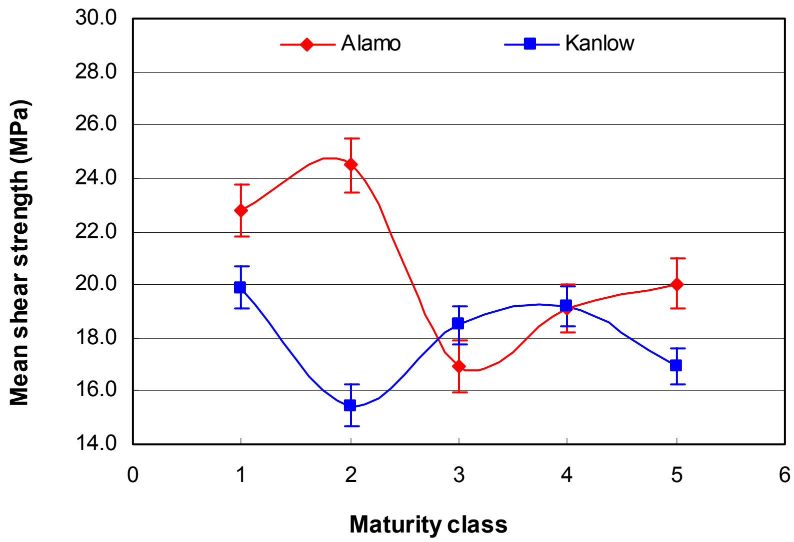

Figure 4.8 Shear strength variations with maturity class for two switchgrass varieties. Error bars on data points indicate plus/minus one standard deviation

Table 4.9 Pearson correlation coefficients between switchgrass tensile and shear strength versus diameter/thickness

Variable	Count	Correlation Coeff	Prob
Tensile Strength vs. Diameter	421	-0.2006	0.0000
Tensile Strength vs. Thickness	423	-0.5370	0.0000
Shear Strength vs. Diameter	437	-0.0464	0.3334
Shear Strength vs. Thickness	437	0.0042	0.9302

shear tests (Tables 4.10). Moisture content versus time after harvest class showed a strong, similar inverse relationship for both tensile and shear tests. These similarities may be interpreted as consistent test conditions for tensile and shear tests.

ANOVA showed statistically different moisture contents for the different classes of time after harvest ($P < 0.0001$). Mean separation (Table 4.11) showed statistically different moisture contents for each class of time after harvest. The data trend shown in Figure 4.9 and Figure 4.10 confirmed these results.

It can be concluded that the drying process was also uniform for both Alamo and Kanlow varieties. Hours after class 6 are slightly different due to the less samples in the experiment for this class, which might cause error. When time after harvest class was greater than five, the moisture content reduction was very low indicating the near comparable tensile and shear tests were consistent.

Tables 4.10 Pearson correlation coefficients of moisture content versus time after harvest for Alamo and Kanlow switchgrass varieties in tensile and shear test

Variable	Variety	Count	Correlation Coff	Prob
Moisture content vs. time after harvest in tensile tests	Alamo	217	-0.8341	0.0000
	Kanlow	211	-0.8500	0.0000
	Combined Alamo and Kanlow	428	-0.8667	0.0000
Moisture content vs. time after harvest in shear tests	Alamo	216	-0.8400	0.0000
	Kanlow	220	-0.8500	0.0000
	Combined Alamo and Kanlow	436	-0.8600	0.0000

Table 4.11 Moisture content versus hours-after-harvest class in tensile and shear test of individual stems of Alamo and Kanlow

Hours after harvest class	Tensile test: Mean moisture content (w.b. %) (Std. Dev.)		Shear test: Mean moisture content (w.b. %) (Std. Dev.)	
	Alamo	Kanlow	Alamo	Kanlow
1 (2 h for tensile) (6 h for shear)	56.4 A[1] (±5.9)	59.9 A (±5.8)	54.2 A (±7.7)	59.8 A (±5.9)
2 (26 h for tensile) (30 h for shear)	45.6 B (±6.4)	48.8 B (±5.2)	46.1 B (±6.5)	48.3 B (±6.2)
3 (74 h for tensile) (78 h for shear)	37.9 C (±6.9)	33.2 C (±8.3)	37.0 C (±8.6)	37.6 C (±10.5)
4 (146 h for tensile) (150 h for shear)	21.4 D (±8.9)	21.5 D (±10.5)	22.0 D (±8.6)	21.5 D (±9.0)
5 (242 h for tensile) (246 h for shear)	11.4 E (±3.5)	13.6 E (±4.8)	11.9 E (±4.3)	14.7 E (±5.5)
6 (386 h for tensile) (390 h for shear)	9.4 E (±2.2)	13.1 DE (±1.2)	9.0 E (±0.4)	12.1 E (±1.1)

[1]Uppercase alpha letters indicate column-wise mean separation

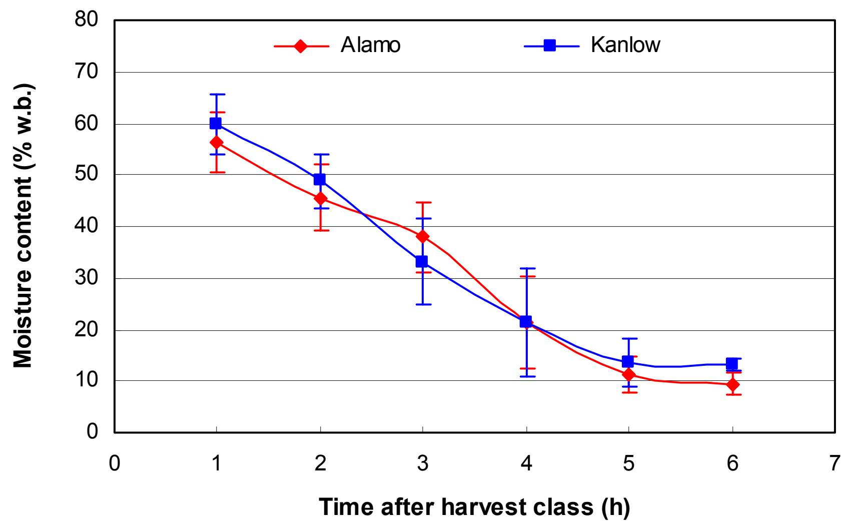

Figure 4.9 Moisture content versus time after harvest class in tensile test Error bars on data points indicate plus/minus one standard deviation

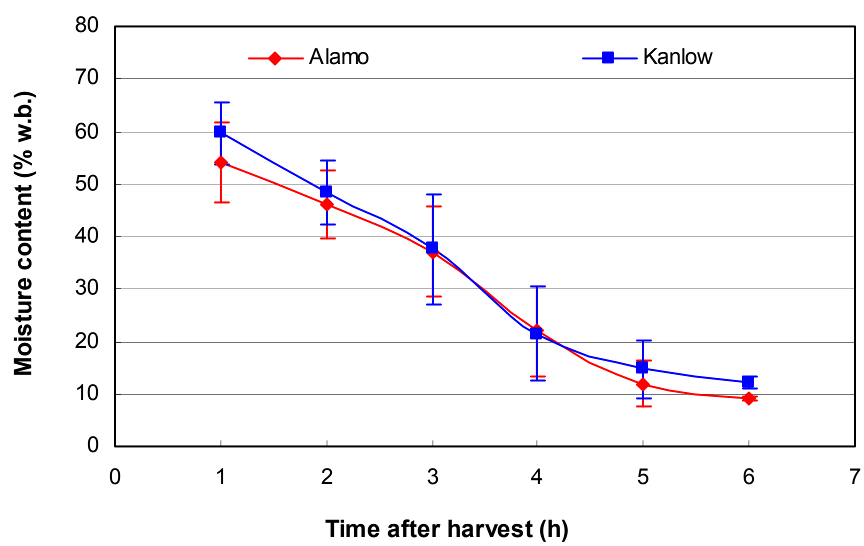

Figure 4.10 Moisture content variations with hours after harvest class in shear test Error bars on data points indicate plus/minus one standard deviation

Moisture content versus maturity class

Table 4.12 shows that mean moisture content was consistent among the different maturity classes for the two switchgrass varieties. The means of the moisture content for any maturity class were the same (P = 0.2). Mean separation further confirmed this relationship with the same letter group A. Mean moisture contents had almost no change during the two and half month growing season. This may be of interest to managers of switchgrass harvest and process (drying) systems.

Thickness and diameter versus time after harvest class

Diameter and thickness slightly decreased as time after harvest increased. Both P values in ANOVA test were less than 0.01, which indicated there was significant difference among the means of the diameter and thickness for any time after harvest class. Mean separation analysis (Table 4.13) further confirmed results with different letter groups. Diameter and thickness decreased as the switchgrass dried in the lab. The Y-Bar shown in Figure 4.11 were standard deviations corresponding with each diameter and thickness data points. Standard deviations of diameter were larger than thickness possibly because of increased cross-sectional dimension variation across the hollow section associated with diameter. Switchgrass stems were not uniform in shape and cross section. Switchgrass cross-section may not have been exactly circular.

Thickness and diameter versus maturity class

Diameter was consistent among the different maturity classes for the combined data on the two switchgrass verities. The P value in ANOVA test was about 0.65, which

Table 4.12 Moisture content variation with maturity class

Maturity class	Count	Mean moisture content (% w.b.) (Std. Dev.)
1 (96 days for Alamo) (103 daysfor Kanlow)	154	37.5513 A[1] (±18.3368)
2 (110 days for Alamo) (117 days for Kanlow)	156	33.8610 A (±16.6315)
3 (124 days for Alamo) (131 days for Kanlow)	175	33.9911 A (±18.5325)
4 (138 days for Alamo) (145 days for Kanlow)	180	37.0487 A (±17.0230)
5 (145 days for Alamo) (159 days.for Kanlow)	199	35.2397 A (±18.9331)

[1]Uppercase alpha letters indicate column-wise mean separation

Table 4.13 Diameter and thickness variation with hours after harvest class

Hours after harvest class	Count	Diameter (m) (Std. Dev.)	Thickness (m) (Std. Dev.)
1	181	0.003723 A[1] (±0.000536)	0.000812 A (±0.000186)
2	174	0.003631 AB (±0.000528)	0.000725 B (±0.000149)
3	164	0.003617 AB (±0.000541)	0.000713 BC (±0.000154)
4	187	0.003485 BC (±0.000630)	0.000665 CD (±0.000154)
5	110	0.003390 C (±0.000719)	0.000642 D (±0.000199)
6	30	0.003383 BC (±0.000540)	0.000586 D (±0.000159)

[1]Uppercase alpha letters indicate column-wise mean separation

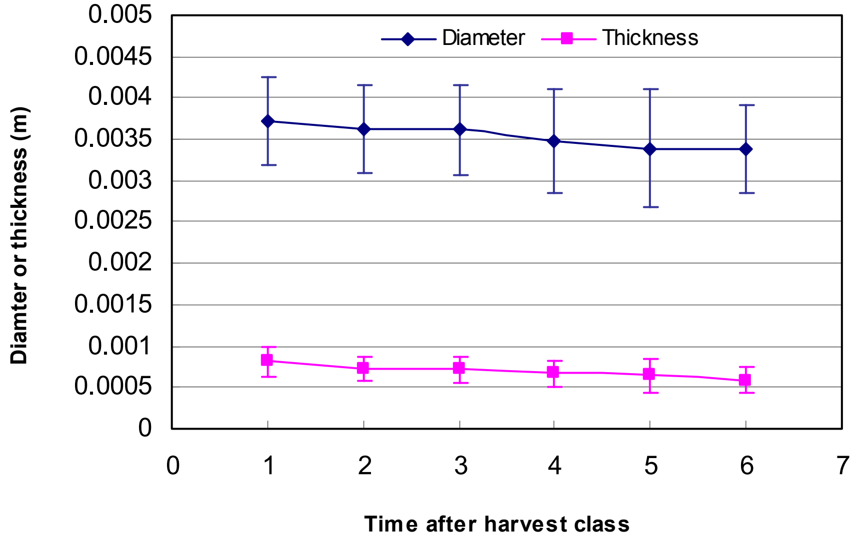

Figure 4.11 Diameter and thickness versus time after harvest class. Error bars on data points indicate plus/minus one standard deviation

indicated that this relation was not statistically significant. For thickness tests, the P value in ANOVA test was less than 0.01, which indicated there was significant difference among the means of the thickness for any maturity class.

Mean separation analysis revealed that thickness produced different main groups but diameter gave one statistical group (Table 4.14. One interpretation was that selection of individual stems during sampling yielded uniform size stems throughout the test period. In other word, the sampling process was consistent. Though separate mean groups were observed with thickness, the maturity class variation did not produce a clear trend with both thickness and diameter for both switchgrass varieties (Figure 4.12).

Table 4.14 Diameter and thickness variation with maturity class

Maturity Class	Count	Diameter (m) (Std. Dev.)	Thickness (m) (Std. Dev.)
1	156	0.003540 A[1] (±0.000635)	0.000631 D (±0.000171)
2	156	0.003571 A (±0.000539)	0.000683 CD (±0.000186)
3	175	0.003622 A (±0.000602)	0.000784 A (±0.000214)
4	180	0.003532 A (±0.000589)	0.000735 AB (±0.000145)
5	199	0.003565 A (±0.000600)	0.000706 BC (±0.000129)

[1]Uppercase alpha letters indicate column-wise mean separation

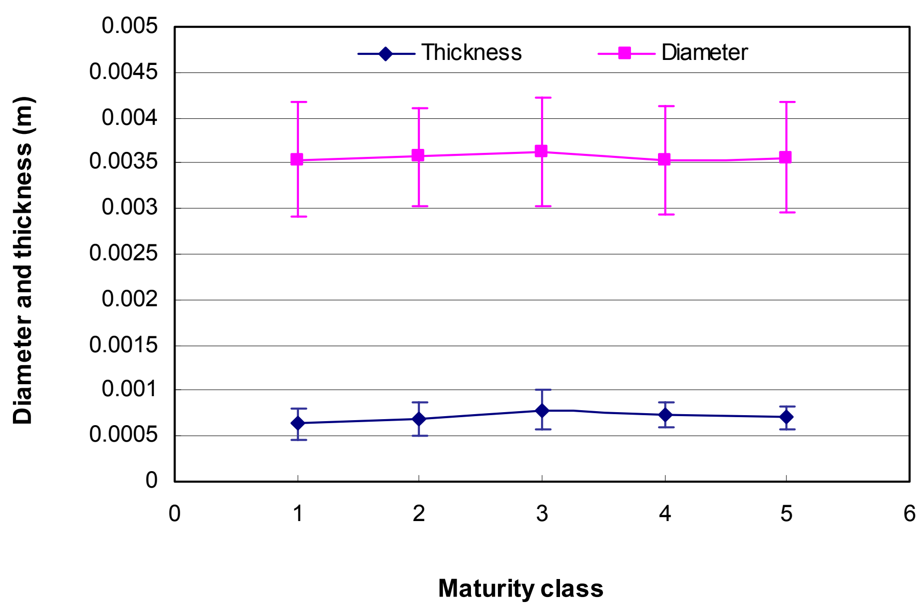

Figure 4.12 Diameter and thickness variation with maturity

Thickness and diameter variation with moisture content

Table 4.15 shows that both diameter and thickness had a direct relation with moisture content. Pearson correlation coefficients were both positive and highly significant.

Width versus variety

Test cross-section width was held consistent for both varieties (Table 4.16). The width was not significantly different for the two varieties (P = 0.4356). Therefore, consistent width was one indicator that the manual sample preparation was conducted in a uniform manner.

Width versus maturity

Test cross-section widths were consistent among maturity classes (Table 4.17). The width was the same among all maturity classes for Alamo (P = 0.1593) and for Kanlow (P = 0.2278). Thereby indicating uniform sample preparation for the different switchgrass varieties throughout the experiment.

Table 4.15 Pearson correlation coefficients for diameter and thickness versus moisture content for data combined of two switchgrass varieties.

Variables (Combined Alamo and Kanlow)	**Count**	**Correlation Coeff**	**Prob**
Diameter vs. Moisture Content	862	0.2393	0.0000
Thickness vs. Moisture Content	864	0.3029	0.0000

Table 4.16 Comparison between width in Alamo and Kanlow varieties

Variety	**Count**	**Mean Width (m)**	**Std. Dev (m)**
Alamo	216	0.001636 A[1]	0.000416
Kanlow	211	0.001668 A	0.000451

[1] Uppercase alpha letters indicate column-wise mean separation

Table 4.17 Comparison between widths in different maturity classes

	Alamo		**Kanlow**	
Maturity Class	**Count**	**Mean Width (m) Std. Dev (m)**	**Count**	**Mean Width (m) Std. Dev (m)**
1	42	0.001589 A[1] (±0.000357)	35	0.001694 A (±0.000338)
2	32	0.001561 A (±0.000449)	44	0.001758 A (±0.000466)
3	43	0.001775 A (±0.000461)	45	0.001613 A (±0.000529)
4	52	0.001621 A (±0.000450)	38	0.001733 A (±0.000473)
5	47	0.001616 A (±0.000340)	49	0.001570 A (±0.000399)

[1] Uppercase alpha letters indicate column-wise mean separation

V. Summary

Individual stems of switchgrass samples were tested for tensile and shear strengths throughout a cropping season so as to resemble switchgrass properties available for biomass processing. Representative processing conditions were organized and statistically tested based on switchgrass variety, maturity, elapsed time after harvest, moisture content, stem diameter and stem thickness. Observations among the factors that contributed to consistent test conditions and validity were identified.

- Mean tensile strength and shear strength were significantly different for the two switchgrass varieties of Alamo and Kanlow.
- Mean shear strength was approximately one-fifth of the tensile strength. Thus, a shear dominant size reduction operation was expected to be much more energy efficient than a tensile- dominant size reduction process.
- Mean tensile strength increased as mean moisture content decreased for both Alamo and Kanlow switchgrass varieties. Mean shear strength did not show a clear trend with the change in mean moisture content.
- Tensile strength increased two-fold as elapsed time after harvest increased from 2 to 386 hours. Shear strength was relatively insensitive to elapsed time after harvest.
- Tensile strength versus maturity relations were consistent between the varieties. However, Alamo variety was more sensitive to maturity than Kanlow variety based on shear strength.
- Tensile strength was inversely related to stem thickness and stem diameter.

- Uniform desiccation of stems due to time after harvest was observed for tensile and shear test even though these tests were conducted at correspondingly different times after harvest. Test conditions were consistent between tensile and shear tests.
- When time after harvest exceeded about 245 hours, moisture content of switchgrass nearly reached equilibrium moisture content for the laboratory storage conditions.
- Mean moisture content was consistent among the different maturity classes for the two switchgrass varieties indicating consistent test conditions throughout the experiment.
- Diameter and thickness slightly decreased as time after harvest increased, possibly due to stem shrinkage phenomena.
- Switchgrass stem diameter was consistent among the different maturity classes for the combined data on the two switchgrass varieties. The manual sampling process yielded uniform size stems throughout the experiment.
- Switchgrass stem diameter and thickness were directly proportional to moisture content with Pearson correlation coefficients of 0.24 (P = 0.0) and 0.30 (P = 0.0), respectively.
- Test cross-section widths of samples were consistent among varieties and maturity classes, thereby indicating uniform sample preparation for the different switchgrass varieties throughout the experiment.

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Appendix

Tensile test data for Alamo

V	Dia (m)	Thick (m)	Width (m)	MC	Mds	Mcl	HAH	Hcl	Force (N)	Area (m^2)	TS(N/m^2)
A	0.0030480	0.0008890	0.0012700	0.6046	96	6	2	1	3.4456E+01	1.1290E-06	3.0518E+07
A	0.0038100	0.0006350	0.0017780	0.6027	96	6	2	1	6.9125E+01	1.1290E-06	6.1225E+07
A	0.0031750	0.0005080	0.0015240	0.6284	96	6	2	1	5.9232E+01	7.7419E-07	7.6508E+07
A	0.0029210	0.0007620	0.0014224	0.5910	96	6	2	1	8.4155E+01	1.0839E-06	7.7644E+07
A	0.0043180	0.0008890	0.0024384	0.6213	96	6	2	1	7.0584E+01	2.1677E-06	3.2561E+07
A	0.0035560	0.0007620	0.0023368	0.6201	96	6	2	1	9.2442E+01	1.7806E-06	5.1915E+07
A	0.0033020	0.0008890	0.0022352	0.5975	96	6	2	1	7.2888E+01	1.9871E-06	3.6681E+07
A	0.0027940	0.0008128	0.0012954	0.6009	96	6	2	1	2.9202E+01	1.0529E-06	2.7735E+07
A	0.0041910	0.0007620	0.0016002	0.4684	96	6	26	2	8.7105E+01	1.2194E-06	7.1435E+07
A	0.0027940	0.0005588	0.0013970	0.4882	96	6	26	2	5.1590E+01	7.8064E-07	6.6087E+07
A	0.0030988	0.0004318	0.0016764	0.5007	96	6	26	2	6.1318E+01	7.2387E-07	8.4709E+07
A	0.0031750	0.0007112	0.0015240	0.4781	96	6	26	2	9.6579E+01	1.0839E-06	8.9106E+07
A	0.0033020	0.0008128	0.0015494	0.6283	96	6	26	2	6.4014E+01	1.2594E-06	5.0831E+07
A	0.0030480	0.0006350	0.0015240	0.6104	96	6	26	2	5.8578E+01	9.6774E-07	6.0531E+07
A	0.0026670	0.0005334	0.0016510	0.5516	96	6	26	2	5.1688E+01	8.8064E-07	5.8694E+07
A	0.0025908	0.0004826	0.0015240	0.4305	96	6	26	2	4.0750E+01	7.3548E-07	5.5406E+07
A	0.0036068	0.0005334	0.0012700	0.4565	96	6	74	3	3.8833E+01	6.7742E-07	5.7325E+07
A	0.0035560	0.0006604	0.0016510	0.5352	96	6	74	3	9.8608E+01	1.0903E-06	9.0439E+07
A	0.0033782	0.0007112	0.0016510	0.4529	96	6	74	3	1.1933E+02	1.1742E-06	1.0163E+08
A	0.0036830	0.0006096	0.0013970	0.5339	96	6	74	3	9.1588E+01	8.5161E-07	1.0755E+08
A	0.0041148	0.0005334	0.0017780	0.4235	96	6	74	3	1.1376E+02	9.4839E-07	1.1995E+08
A	0.0035560	0.0006604	0.0013208	0.3850	96	6	74	3	1.0364E+02	8.7226E-07	1.1882E+08
A	0.0034290	0.0005080	0.0011176	0.3707	96	6	74	3	6.4303E+01	5.6774E-07	1.1326E+08
A	0.0033020	0.0005334	0.0012700	0.4212	96	6	74	3	8.5859E+01	6.7742E-07	1.2674E+08
A	0.0029210	0.0006604	0.0012446	0.4575	96	6	74	3	5.6781E+01	8.2193E-07	6.9083E+07
A	0.0030480	0.0005080	0.0013970	0.3899	96	6	74	3	9.1855E+01	7.0968E-07	1.2943E+08
A	0.0039370	0.0007620	0.0015240	0.4551	96	6	146	4	1.1803E+02	1.1613E-06	1.0164E+08
A	0.0029972	0.0007620	0.0010668	0.2479	96	6	146	4	7.4899E+01	8.1290E-07	9.2138E+07
A	0.0033528	0.0007620	0.0015748	0.3739	96	6	146	4	1.3868E+02	1.2000E-06	1.1557E+08
A	0.0034290	0.0005080	0.0010160	0.3203	96	6	146	4	8.4649E+01	5.1613E-07	1.6401E+08
A	0.0038608	0.0008128	0.0012954	0.3675	96	6	146	4	9.7037E+01	1.0529E-06	9.2162E+07
A	0.0033274	0.0005461	0.0012954	0.4009	96	6	146	4	6.7848E+01	7.0742E-07	9.5910E+07
A	0.0035560	0.0006350	0.0014732	0.4258	96	6	146	4	1.1365E+02	9.3548E-07	1.2149E+08
A	0.0027940	0.0005334	0.0010414	0.2311	96	6	146	4	7.0028E+01	5.5548E-07	1.2607E+08
A	0.0038608	0.0007620	0.0020320	0.0881	96	6	386	6	1.2350E+02	1.5484E-06	7.9758E+07
A	0.0038100	0.0007620	0.0016510	0.0837	96	6	386	6	1.3561E+02	1.2581E-06	1.0779E+08
A	0.0043180	0.0007620	0.0023114	0.1487	96	6	386	6	3.3209E+02	1.7613E-06	1.8855E+08
A	0.0031750	0.0006350	0.0020320	0.0842	96	6	386	6	1.8288E+02	1.2903E-06	1.4173E+08
A	0.0041910	0.0007620	0.0018034	0.0875	96	6	386	6	1.6096E+02	1.3742E-06	1.1713E+08
A	0.0038100	0.0006350	0.0018288	0.0921	96	6	386	6	2.0619E+02	1.1613E-06	1.7755E+08
A	0.0040640	0.0008890	0.0021590	0.0839	96	6	386	6	1.6996E+02	1.9194E-06	8.8549E+07
A	0.0041910	0.0007620	0.0018034	0.0875	96	6	386	6	1.6096E+02	1.3742E-06	1.1713E+08
	.	.	.	.	.		.		.	.	.
A	0.0041402	0.0008128	0.0010160	0.4334	110	7	2	1	8.7603E+01	8.2581E-07	1.0608E+08
A	0.0040640	0.0007620	0.0017780	0.5999	110	7	2	1	1.3341E+02	1.3548E-06	9.8473E+07
A	0.0041148	0.0005080	0.0015240	0.5778	110	7	2	1	7.8942E+01	7.7419E-07	1.0197E+08
A	0.0038100	0.0005334	0.0012700	0.5576	110	7	2	1	1.0290E+02	6.7742E-07	1.5190E+08
A	0.0041148	0.0007620	0.0015240	0.4901	110	7	2	1	1.1226E+02	1.1613E-06	9.6668E+07

A	0.0038608	0.0005842	0.0023368	0.5443	110	7	2	1	1.5459E+02	1.3652E-06	1.1324E+08
A	0.0041148	0.0007874	0.0015240	0.5477	110	7	2	1	1.0896E+02	1.2000E-06	9.0799E+07
A	0.0038608	0.0008128	0.0016510	0.5432	110	7	2	1	1.1543E+02	1.3419E-06	8.6015E+07
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0038100	0.0006350	0.0024130	0.3610	110	7	26	2	1.8175E+02	1.5323E-06	1.1862E+08
A	0.0033020	0.0007620	0.0012700	0.3509	110	7	74	3	8.7416E+01	9.6774E-07	9.0330E+07
A	0.0039116	0.0006096	0.0017780	0.4395	110	7	74	3	1.3235E+02	1.0839E-06	1.2211E+08
A	0.0034290	0.0005334	0.0007112	0.4207	110	7	74	3	6.2729E+01	3.7935E-07	1.6536E+08
A	0.0035560	0.0005588	0.0019050	0.3829	110	7	74	3	1.4127E+02	1.0645E-06	1.3271E+08
A	0.0038100	0.0006350	0.0014732	0.4306	110	7	74	3	8.2995E+01	9.3548E-07	8.8718E+07
A	0.0031750	0.0004064	0.0017018	0.4390	110	7	74	3	1.0630E+02	6.9161E-07	1.5370E+08
A	0.0031750	0.0005080	0.0007112	0.4107	110	7	74	3	5.0572E+01	3.6129E-07	1.3998E+08
A	0.0038100	0.0006350	0.0014732	0.4306	110	7	74	3	8.2995E+01	9.3548E-07	8.8718E+07
A	0.0038100	0.0005461	0.0010160	0.2954	110	7	146	4	1.0306E+02	5.5484E-07	1.8574E+08
A	0.0037592	0.0005842	0.0015748	0.3868	110	7	146	4	1.1566E+02	9.2000E-07	1.2572E+08
A	0.0035814	0.0007620	0.0019812	0.1635	110	7	146	4	1.5561E+02	1.5097E-06	1.0308E+08
A	0.0026670	0.0005080	0.0011176	0.1244	110	7	146	4	9.0579E+01	5.6774E-07	1.5954E+08
A	0.0038100	0.0004826	0.0013716	0.2621	110	7	146	4	1.3586E+02	6.6193E-07	2.0524E+08
A	0.0034544	0.0005334	0.0009906	0.1534	110	7	146	4	6.0460E+01	5.2839E-07	1.1442E+08
A	0.0040640	0.0007620	0.0022860	0.2593	110	7	146	4	1.8309E+02	1.7419E-06	1.0511E+08
A	0.0033020	0.0006350	0.0020066	0.2196	110	7	146	4	1.7179E+02	1.2742E-06	1.3482E+08
A	0.0030480	0.0004318	0.0015240	0.1199	110	7	242	5	8.2056E+01	6.5806E-07	1.2469E+08
A	0.0024130	0.0003048	0.0012700	0.1150	110	7	242	5	6.9846E+01	3.8710E-07	1.8043E+08
A	0.0029972	0.0003556	0.0012700	0.1506	110	7	242	5	8.5668E+01	4.5161E-07	1.8969E+08
A	0.0029972	0.0003556	0.0012700	0.1506	110	7	242	5	8.5668E+01	4.5161E-07	1.8969E+08
A	0.0033782	0.0005080	0.0013716	0.1040	110	7	242	5	9.7215E+01	6.9677E-07	1.3952E+08
A	0.0037084	0.0005842	0.0022860	0.1210	110	7	242	5	2.0944E+02	1.3355E-06	1.5683E+08
A	0.0035560	0.0005080	0.0017780	0.1391	110	7	242	5	1.4727E+02	9.0322E-07	1.6305E+08
A	0.0033528	0.0004572	0.0020320	0.1088	110	7	242	5	1.1354E+02	9.2903E-07	1.2221E+08
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A	0.0039116	0.0011176	0.0019431	0.5240	124	8	2	1	1.5627E+02	2.1716E-06	7.1960E+07
A	0.0034163	0.0008509	0.0017272	0.5636	124	8	2	1	1.0818E+02	1.4697E-06	7.3608E+07
A	0.0028448	0.0011430	0.0021590	0.5546	124	8	2	1	7.3733E+01	2.4677E-06	2.9879E+07
A	0.0028321	0.0007366	0.0021590	0.5594	124	8	2	1	1.1719E+02	1.5903E-06	7.3691E+07
A	0.0037465	0.0009525	0.0021971	0.5627	124	8	2	1	1.3596E+02	2.0927E-06	6.4969E+07
A	0.0033147	0.0010541	0.0022606	0.5058	124	8	2	1	9.0854E+01	2.3829E-06	3.8128E+07
A	0.0038608	0.0007366	0.0014478	0.5486	124	8	2	1	9.9306E+01	1.0665E-06	9.3118E+07
A	0.0041529	0.0008255	0.0021717	0.5000	124	8	2	1	1.8139E+02	1.7927E-06	1.0118E+08
A	0.0041656	0.0007747	0.0028829	0.4547	124	8	26	2	1.8369E+02	2.2334E-06	8.2247E+07
A	0.0037465	0.0007239	0.0016637	0.4612	124	8	26	2	9.8012E+01	1.2044E-06	8.1381E+07
A	0.0034671	0.0006477	0.0020320	0.4391	124	8	26	2	7.2839E+01	1.3161E-06	5.5344E+07
A	0.0041656	0.0007747	0.0028829	0.4547	124	8	26	2	1.8369E+02	2.2334E-06	8.2247E+07
A	0.0034925	0.0009271	0.0015494	0.3589	124	8	26	2	1.0812E+02	1.4365E-06	7.5268E+07
A	0.0042926	0.0006096	0.0020574	0.4465	124	8	26	2	1.5239E+02	1.2542E-06	1.2150E+08
A	0.0038481	0.0007747	0.0016129	0.4042	124	8	26	2	1.1855E+02	1.2495E-06	9.4876E+07
A	0.0040386	0.0011557	0.0018288	0.4316	124	8	26	2	1.4015E+02	2.1135E-06	6.6310E+07

A	0.0032766	0.0006731	0.0013462	0.2950	124	8	74	3	1.0808E+02	9.0613E-07	1.1928E+08
A	0.0039624	0.0008890	0.0014351	0.2994	124	8	74	3	1.3038E+02	1.2758E-06	1.0220E+08
A	0.0038481	0.0013081	0.0020574	0.2808	124	8	74	3	2.3423E+02	2.6913E-06	8.7034E+07
A	0.0037846	0.0005842	0.0018669	0.3442	124	8	74	3	1.1888E+02	1.0906E-06	1.0900E+08
A	0.0032766	0.0006731	0.0013462	0.2950	124	8	74	3	1.0808E+02	9.0613E-07	1.1928E+08
A	0.0033909	0.0007747	0.0015367	0.4127	124	8	74	3	9.7687E+01	1.1905E-06	8.2057E+07
A	0.0043752	0.0009779	0.0019050	0.2661	124	8	74	3	1.3464E+02	1.8629E-06	7.2273E+07
A	0.0033909	0.0007366	0.0020701	0.3768	124	8	74	3	1.1506E+02	1.5248E-06	7.5455E+07
A	0.0035814	0.0010160	0.0014351	0.4483	124	8	74	3	9.6784E+01	1.4581E-06	6.6378E+07
A	0.0027305	0.0006604	0.0012192	0.1058	124	8	146	4	8.8199E+01	8.0516E-07	1.0954E+08
A	0.0029718	0.0008128	0.0012319	0.1333	124	8	146	4	9.1112E+01	1.0013E-06	9.0995E+07
A	0.0035052	0.0006096	0.0012319	0.1023	124	8	146	4	1.2683E+02	7.5097E-07	1.6889E+08
A	0.0036068	0.0009652	0.0018161	0.0976	124	8	146	4	1.2451E+02	1.7529E-06	7.1031E+07
A	0.0034417	0.0008509	0.0024511	0.1931	124	8	146	4	9.4462E+01	2.0856E-06	4.5292E+07
A	0.0036195	0.0007239	0.0023749	0.1821	124	8	146	4	1.3866E+02	1.7192E-06	8.0654E+07
A	0.0043815	0.0009525	0.0017526	0.2121	124	8	146	4	1.9053E+02	1.6694E-06	1.1413E+08
A	0.0037719	0.0006731	0.0020955	0.1235	124	8	146	4	1.6671E+02	1.4105E-06	1.1819E+08
A	0.0037719	0.0006731	0.0020955	0.1235	124	8	146	4	1.6671E+02	1.4105E-06	1.1819E+08
A	0.0033401	0.0007747	0.0011811	0.1036	124	8	242	5	1.1039E+02	9.1500E-07	1.2065E+08
A	0.0028575	0.0004191	0.0011176	0.1137	124	8	242	5	6.3654E+01	4.6839E-07	1.3590E+08
A	0.0027178	0.0006096	0.0011303	0.1018	124	8	242	5	8.8839E+01	6.8903E-07	1.2893E+08
A	0.0028829	0.0006223	0.0022098	0.0925	124	8	242	5	1.2572E+02	1.3752E-06	9.1422E+07
A	0.0041275	0.0007620	0.0010541	0.0855	124	8	242	5	8.9636E+01	8.0322E-07	1.1159E+08
A	0.0029083	0.0005334	0.0016510	0.1033	124	8	242	5	8.5913E+01	8.8064E-07	9.7557E+07
A	0.0042926	0.0012192	0.0015875	0.0939	124	8	242	5	1.1789E+02	1.9355E-06	6.0910E+07
A	0.0033020	0.0005334	0.0013589	0.0949	124	8	242	5	8.5397E+01	7.2484E-07	1.1781E+08
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A	0.0037211	0.0007112	0.0017526	0.5201	138	9	2	1	7.2515E+01	1.2465E-06	5.8177E+07
A	0.0028829	0.0006477	0.0014351	0.5956	138	9	2	1	5.1870E+01	9.2951E-07	5.5804E+07
A	0.0040005	0.0011557	0.0027940	0.6278	138	9	2	1	1.5746E+02	3.2290E-06	4.8763E+07
A	0.0041275	0.0009144	0.0027051	0.5221	138	9	2	1	1.5963E+02	2.4735E-06	6.4536E+07
A	0.0036322	0.0007620	0.0019685	0.5784	138	9	2	1	9.6014E+01	1.5000E-06	6.4010E+07
A	0.0032766	0.0008128	0.0013970	0.5986	138	9	2	1	5.0576E+01	1.1355E-06	4.4541E+07
A	0.0041529	0.0009398	0.0021336	0.5761	138	9	2	1	6.9009E+01	2.0052E-06	3.4416E+07
A	0.0041402	0.0009398	0.0017272	0.5972	138	9	2	1	1.1047E+02	1.6232E-06	6.8054E+07
A	0.0037973	0.0008509	0.0013208	0.5724	138	9	2	1	7.0575E+01	1.1239E-06	6.2797E+07
A	0.0041021	0.0009144	0.0014478	0.4048	138	9	26	2	1.3784E+02	1.3239E-06	1.0412E+08
A	0.0042418	0.0010414	0.0023749	0.4454	138	9	26	2	2.1766E+02	2.4732E-06	8.8006E+07
A	0.0046101	0.0009779	0.0017399	0.4241	138	9	26	2	1.8569E+02	1.7015E-06	1.0913E+08
A	0.0041021	0.0009144	0.0019050	0.4805	138	9	26	2	1.3151E+02	1.7419E-06	7.5497E+07
A	0.0046101	0.0009779	0.0017399	0.4241	138	9	26	2	1.8569E+02	1.7015E-06	1.0913E+08
A	0.0037084	0.0008636	0.0015494	0.4892	138	9	26	2	7.7194E+01	1.3381E-06	5.7691E+07
A	0.0038989	0.0009779	0.0012954	0.4435	138	9	26	2	8.2830E+01	1.2668E-06	6.5387E+07
A	0.0042291	0.0007620	0.0016510	0.4879	138	9	26	2	1.2474E+02	1.2581E-06	9.9150E+07
A	0.0038989	0.0008636	0.0018796	0.4789	138	9	26	2	1.2710E+02	1.6232E-06	7.8303E+07
A	0.0031877	0.0006477	0.0016637	0.4883	138	9	26	2	9.2523E+01	1.0776E-06	8.5862E+07
A	0.0042291	0.0007620	0.0016510	0.4879	138	9	26	2	1.2474E+02	1.2581E-06	9.9150E+07
A	0.0031877	0.0006477	0.0016637	0.4883	138	9	26	2	9.2523E+01	1.0776E-06	8.5862E+07
A	0.0038608	0.0008255	0.0017653	0.4088	138	9	74	3	1.2663E+02	1.4573E-06	8.6894E+07
A	0.0033655	0.0006477	0.0020066	0.3857	138	9	74	3	1.2796E+02	1.2997E-06	9.8456E+07
A	0.0036703	0.0008128	0.0013081	0.3403	138	9	74	3	1.0971E+02	1.0632E-06	1.0319E+08
A	0.0041656	0.0008382	0.0018415	0.3933	138	9	74	3	1.5818E+02	1.5436E-06	1.0248E+08

A	0.0030226	0.0005588	0.0017526	0.4110	138	9	74	3	1.0814E+02	9.7935E-07	1.1042E+08
A	0.0039624	0.0008001	0.0019939	0.3077	138	9	74	3	1.5387E+02	1.5953E-06	9.6449E+07
A	0.0033401	0.0007366	0.0017780	0.3702	138	9	74	3	1.3733E+02	1.3097E-06	1.0486E+08
A	0.0038608	0.0007747	0.0015494	0.2869	138	9	74	3	1.4160E+02	1.2003E-06	1.1797E+08
A	0.0040386	0.0009906	0.0020574	0.4226	138	9	74	3	1.5448E+02	2.0381E-06	7.5796E+07
A	0.0034036	0.0007366	0.0011684	0.3385	138	9	74	3	8.1851E+01	8.6064E-07	9.5105E+07
A	0.0025654	0.0005842	0.0014478	0.2255	138	9	146	4	1.1330E+02	8.4581E-07	1.3395E+08
A	0.0028575	0.0006350	0.0013208	0.2287	138	9	146	4	9.0846E+01	8.3871E-07	1.0832E+08
A	0.0033528	0.0006604	0.0018034	0.1252	138	9	146	4	1.6221E+02	1.1910E-06	1.3620E+08
A	0.0024638	0.0005207	0.0008255	0.2064	138	9	146	4	6.5451E+01	4.2984E-07	1.5227E+08
A	0.0028194	0.0005461	0.0012319	0.2303	138	9	146	4	7.7150E+01	6.7274E-07	1.1468E+08
A	0.0028194	0.0004445	0.0010033	0.2303	138	9	146	4	6.6340E+01	4.4597E-07	1.4876E+08
A	0.0024384	0.0005715	0.0005461	0.3033	138	9	146	4	4.6088E+01	3.1210E-07	1.4767E+08
A	0.0033528	0.0010668	0.0007747	0.1556	138	9	146	4	6.9000E+01	8.2645E-07	8.3490E+07
A	0.0028194	0.0005588	0.0009144	0.1780	138	9	146	4	5.2062E+01	5.1097E-07	1.0189E+08
A	0.0025908	0.0004445	0.0011811	0.1423	138	9	146	4	5.0887E+01	5.2500E-07	9.6929E+07
A	0.0036703	0.0007747	0.0019304	0.1917	138	9	146	4	1.5740E+02	1.4955E-06	1.0525E+08
A	0.0040386	0.0007747	0.0010033	0.2310	138	9	146	4	6.8520E+01	7.7726E-07	8.8156E+07
A	0.0039624	0.0007874	0.0014986	0.1696	138	9	146	4	1.2105E+02	1.1800E-06	1.0259E+08
A	0.0035433	0.0008636	0.0015621	0.0783	138	9	242	5	1.2757E+02	1.3490E-06	9.4568E+07
A	0.0028702	0.0005715	0.0016002	0.1198	138	9	242	5	6.6781E+01	9.1451E-07	7.3023E+07
A	0.0044831	0.0007112	0.0020066	0.0829	138	9	242	5	1.3583E+02	1.4271E-06	9.5180E+07
A	0.0024638	0.0005080	0.0016383	0.0940	138	9	242	5	1.3730E+02	8.3226E-07	1.6498E+08
A	0.0037719	0.0007112	0.0013208	0.0870	138	9	242	5	1.0670E+02	9.3935E-07	1.1359E+08
A	0.0035306	0.0006223	0.0024257	0.1292	138	9	242	5	8.9809E+01	1.5095E-06	5.9495E+07
A	0.0027940	0.0005080	0.0013589	0.1496	138	9	242	5	7.7777E+01	6.9032E-07	1.1267E+08
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A	0.0043688	0.0007112	0.0014351	0.5084	152	10	2	1	9.7469E+01	1.0206E-06	9.5498E+07
A	0.0042291	0.0006985	0.0014859	0.5359	152	10	2	1	1.0955E+02	1.0379E-06	1.0555E+08
A	0.0038227	0.0006985	0.0014986	0.5132	152	10	2	1	7.4120E+01	1.0468E-06	7.0808E+07
A	0.0034925	0.0007239	0.0014351	0.5689	152	10	2	1	8.1900E+01	1.0389E-06	7.8836E+07
A	0.0030988	0.0008636	0.0012446	0.4837	152	10	2	1	7.1456E+01	1.0748E-06	6.6481E+07
A	0.0032512	0.0006223	0.0011938	0.4510	152	10	2	1	8.2403E+01	7.4290E-07	1.1092E+08
A	0.0038735	0.0007874	0.0021463	0.8009	152	10	2	1	1.2040E+02	1.6900E-06	7.1245E+07
A	0.0034417	0.0007366	0.0013462	0.6094	152	10	2	1	6.3703E+01	9.9161E-07	6.4242E+07
A	0.0034036	0.0006985	0.0016891	0.5550	152	10	2	1	9.4026E+01	1.1798E-06	7.9694E+07
A	0.0038989	0.0008382	0.0016256	0.3567	152	10	26	2	1.2858E+02	1.3626E-06	9.4368E+07
A	0.0032385	0.0006477	0.0016256	0.5051	152	10	26	2	8.4155E+01	1.0529E-06	7.9927E+07
A	0.0032639	0.0006858	0.0010922	0.3428	152	10	26	2	5.7368E+01	7.4903E-07	7.6590E+07
A	0.0032385	0.0009652	0.0016764	0.4024	152	10	26	2	1.0129E+02	1.6181E-06	6.2597E+07
A	0.0025781	0.0005461	0.0012446	0.4427	152	10	26	2	5.1764E+01	6.7968E-07	7.6159E+07
A	0.0032385	0.0007620	0.0014986	0.4189	152	10	26	2	1.2172E+02	1.1419E-06	1.0659E+08
A	0.0038100	0.0006223	0.0016764	0.4551	152	10	26	2	7.6927E+01	1.0432E-06	7.3740E+07
A	0.0039116	0.0006858	0.0011684	0.5065	152	10	26	2	6.9365E+01	8.0129E-07	8.6567E+07
A	0.0031877	0.0007747	0.0011049	0.3973	152	10	26	2	5.6470E+01	8.5597E-07	6.5972E+07
A	0.0030734	0.0008001	0.0019050	0.5665	152	10	26	2	1.0626E+02	1.5242E-06	6.9715E+07
A	0.0037846	0.0005969	0.0019558	0.2404	152	10	74	3	1.4361E+02	1.1674E-06	1.2302E+08
A	0.0045847	0.0008636	0.0015113	0.3961	152	10	74	3	1.5730E+02	1.3052E-06	1.2052E+08
A	0.0035560	0.0006731	0.0019177	0.2387	152	10	74	3	1.1706E+02	1.2908E-06	9.0687E+07
A	0.0028321	0.0005842	0.0012065	0.2593	152	10	74	3	5.9206E+01	7.0484E-07	8.3999E+07
A	0.0039370	0.0007722	0.0022352	0.3933	152	10	74	3	1.1932E+02	1.7259E-06	6.9133E+07
A	0.0042291	0.0007239	0.0018288	0.3818	152	10	74	3	1.6913E+02	1.3239E-06	1.2775E+08

A	0.0048387	0.0010033	0.0020320	0.3630	152	10	74	3	1.8390E+02	2.0387E-06	9.0203E+07
A	0.0040767	0.0007620	0.0017653	0.3787	152	10	74	3	1.2149E+02	1.3452E-06	9.0316E+07
A	0.0027305	0.0006858	0.0016637	0.1832	152	10	146	4	1.2368E+02	1.1410E-06	1.0840E+08
A	0.0041148	0.0008382	0.0012827	0.1017	152	10	146	4	8.3017E+01	1.0752E-06	7.7213E+07
A	0.0033909	0.0006096	0.0013716	0.2173	152	10	146	4	8.5494E+01	8.3613E-07	1.0225E+08
A	0.0030226	0.0006223	0.0015621	0.1257	152	10	146	4	1.2138E+02	9.7210E-07	1.2487E+08
A	0.0024638	0.0004445	0.0013970	0.1259	152	10	146	4	7.3600E+01	6.2097E-07	1.1852E+08
A	0.0028448	0.0004572	0.0014859	0.2197	152	10	146	4	7.9418E+01	6.7935E-07	1.1690E+08
A	0.0029083	0.0005588	0.0020066	0.1929	152	10	146	4	7.3600E+01	1.1213E-06	6.5639E+07
A	0.0029083	0.0005588	0.0013208	0.1929	152	10	146	4	6.6696E+01	7.3806E-07	9.0367E+07
A	0.0040894	0.0005842	0.0019558	0.2874	152	10	146	4	1.0954E+02	1.1426E-06	9.5872E+07
A	0.0040259	0.0006096	0.0014732	0.1381	152	10	146	4	1.2828E+02	8.9806E-07	1.4284E+08
A	0.0024765	0.0005842	0.0013462	0.1930	152	10	146	4	8.4356E+01	7.8645E-07	1.0726E+08
A	0.0038481	0.0005842	0.0019304	0.1302	152	10	218	5	1.3817E+02	1.1277E-06	1.2252E+08
A	0.0050292	0.0008001	0.0025654	0.0778	152	10	218	5	1.3100E+02	2.0526E-06	6.3820E+07
A	0.0025146	0.0005461	0.0019050	0.0919	152	10	218	5	7.0424E+01	1.0403E-06	6.7694E+07
A	0.0028702	0.0006223	0.0013716	0.0814	152	10	218	5	7.2110E+01	8.5355E-07	8.4483E+07
A	0.0040640	0.0008763	0.0019177	0.0881	152	10	218	5	1.6283E+02	1.6805E-06	9.6895E+07
A	0.0039624	0.0006477	0.0021082	0.1929	152	10	218	5	1.1628E+02	1.3655E-06	8.5160E+07
A	0.0044704	0.0006858	0.0012065	0.0877	152	10	218	5	8.5299E+01	8.2742E-07	1.0309E+08
A	0.0047625	0.0007366	0.0014859	0.2429	152	10	218	5	1.0278E+02	1.0945E-06	9.3905E+07
A	0.0045720	0.0006985	0.0020574	0.1413	152	10	218	5	1.7698E+02	1.4371E-06	1.2315E+08

Tensile test data for Kanlow

V	Dia (m)	Thick (m)	Width (m)	MC	Mds	Mcl	Hah	Hcl	Force (N)	Area (m^2)	TS (N/m^2)
K	0.0047244	0.0008890	0.0018288	0.6172	103	1	2	1	1.0360E+02	1.6258E-06	6.3724E+07
K	0.0034290	0.0010160	0.0019812	0.5592	103	1	2	1	1.4168E+02	2.0129E-06	7.0384E+07
K	0.0046990	0.0011430	0.0018542	0.5112	103	1	2	1	1.3680E+02	2.1194E-06	6.4550E+07
K	0.0044450	0.0012700	0.0018288	0.4684	103	1	2	1	1.1346E+02	2.3226E-06	4.8849E+07
K	0.0040894	0.0008890	0.0020320	0.5686	103	1	2	1	1.3594E+02	1.8065E-06	7.5251E+07
K	0.0038100	0.0007620	0.0015240	0.4784	103	1	2	1	8.0815E+01	1.1613E-06	6.9591E+07
K	0.0045720	0.0010160	0.0020828	0.5101	103	1	2	1	1.7064E+02	2.1161E-06	8.0637E+07
K	0.0043180	0.0010160	0.0013970	0.5802	103	1	2	1	7.0548E+01	1.4194E-06	4.9705E+07
K	0.0045720	0.0007620	0.0019050	0.5213	103	1	26	2	1.4458E+02	1.4516E-06	9.9597E+07
K	0.0045720	0.0007620	0.0017780	0.4993	103	1	26	2	1.3323E+02	1.3548E-06	9.8335E+07
K	0.0035560	0.0005080	0.0017780	0.5671	103	1	26	2	1.3957E+02	9.0322E-07	1.5452E+08
K	0.0036830	0.0005080	0.0019050	0.5459	103	1	26	2	1.0798E+02	9.6774E-07	1.1158E+08
K	0.0041910	0.0007620	0.0017780	0.5187	103	1	26	2	1.2675E+02	1.3548E-06	9.3552E+07
K	0.0033020	0.0006350	0.0011430	0.5203	103	1	26	2	7.3320E+01	7.2581E-07	1.0102E+08
K	0.0049530	0.0007874	0.0018542	0.5171	103	1	26	2	1.1409E+02	1.4600E-06	7.8145E+07
K	0.0040640	0.0005080	0.0017272	0.3827	103	1	146	4	1.2539E+02	8.7742E-07	1.4291E+08
K	0.0041910	0.0006350	0.0019812	0.3827	103	1	146	4	1.0119E+02	1.2581E-06	8.0435E+07
K	0.0050800	0.0007874	0.0024892	0.4377	103	1	146	4	1.7493E+02	1.9600E-06	8.9252E+07
K	0.0043180	0.0008890	0.0020066	0.3828	103	1	146	4	1.4323E+02	1.7839E-06	8.0293E+07
K	0.0038100	0.0005080	0.0015240	0.3599	103	1	146	4	9.9133E+01	7.7419E-07	1.2805E+08
K	0.0050800	0.0006858	0.0015494	0.4032	103	1	146	4	1.3705E+02	1.0626E-06	1.2898E+08
K	0.0050800	0.0007620	0.0020828	0.4251	103	1	146	4	1.2196E+02	1.5871E-06	7.6843E+07
K	0.0033020	0.0006858	0.0013970	0.2323	103	1	146	4	7.7003E+01	9.5806E-07	8.0373E+07
K	0.0048514	0.0007620	0.0020320	0.2041	103	1	242	5	1.2609E+02	1.5484E-06	8.1436E+07

K	0.0031750	0.0003810	0.0015240	0.1984	103	1	242	5	1.0197E+02	5.8064E-07	1.7561E+08
K	0.0034798	0.0005080	0.0016002	0.2309	103	1	242	5	1.0946E+02	8.1290E-07	1.3465E+08
K	0.0030734	0.0005588	0.0013208	0.2040	103	1	242	5	8.9907E+01	7.3806E-07	1.2181E+08
K	0.0031750	0.0003810	0.0012954	0.1139	103	1	242	5	8.3324E+01	4.9355E-07	1.6883E+08
K	0.0034798	0.0005080	0.0016002	0.2309	103	1	242	5	1.0946E+02	8.1290E-07	1.3465E+08
K	0.0028702	0.0004064	0.0012954	0.1491	103	1	386	6	7.7559E+01	5.2645E-07	1.4732E+08
K	0.0025400	0.0003556	0.0010160	0.1367	103	1	386	6	7.6954E+01	3.6129E-07	2.1300E+08
K	0.0030480	0.0006858	0.0010414	0.1291	103	1	386	6	9.0681E+01	7.1419E-07	1.2697E+08
K	0.0033020	0.0002921	0.0018288	0.1201	103	1	386	6	8.8372E+01	5.3419E-07	1.6543E+08
K	0.0038100	0.0006858	0.0012700	0.1298	103	1	386	6	1.0416E+02	8.7097E-07	1.1960E+08
K	0.0035560	0.0006350	0.0020320	0.1190	103	1	386	6	1.1579E+02	1.2903E-06	8.9738E+07
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K	0.0041529	0.0009398	0.0027813	0.5886	117	2	2	1	7.2510E+01	2.6139E-06	2.7741E+07
K	0.0045339	0.0010795	0.0022479	0.6184	117	2	2	1	1.5966E+02	2.4266E-06	6.5797E+07
K	0.0043434	0.0011938	0.0021844	0.5877	117	2	2	1	1.5883E+02	2.6077E-06	6.0906E+07
K	0.0040767	0.0009144	0.0029464	0.6131	117	2	2	1	1.7602E+02	2.6942E-06	6.5331E+07
K	0.0040767	0.0009144	0.0029464	0.6131	117	2	2	1	1.7602E+02	2.6942E-06	6.5331E+07
K	.	0.0007239	0.0017780	0.5927	117	2	2	1	7.8235E+01	1.2871E-06	6.0784E+07
K	0.0037211	0.0007620	0.0018923	0.6128	117	2	2	1	8.8417E+01	1.4419E-06	6.1318E+07
K	0.0041275	0.0011049	0.0013970	0.4159	117	2	26	2	8.5984E+01	1.5436E-06	5.5705E+07
K	0.0036195	0.0007874	0.0013208	0.4486	117	2	26	2	8.1278E+01	1.0400E-06	7.8152E+07
K	0.0040386	0.0008128	0.0013970	0.4895	117	2	26	2	1.1189E+02	1.1355E-06	9.8536E+07
K	0.0043688	0.0006858	0.0025400	0.5492	117	2	26	2	1.5809E+02	1.7419E-06	9.0758E+07
K	0.0039624	0.0008128	0.0014859	0.4680	117	2	26	2	1.1657E+02	1.2077E-06	9.6519E+07
K	0.0035306	0.0008382	0.0015494	0.3100	117	2	26	2	6.9601E+01	1.2987E-06	5.3593E+07
K	0.0036830	0.0008255	0.0021590	0.4214	117	2	26	2	1.4124E+02	1.7823E-06	7.9250E+07
K	0.0035941	0.0007112	0.0020574	0.4357	117	2	26	2	1.2240E+02	1.4632E-06	8.3652E+07
K	0.0036830	0.0005461	0.0012954	0.2951	117	2	74	3	7.5975E+01	7.0742E-07	1.0740E+08
K	0.0030226	0.0006604	0.0012700	0.2837	117	2	74	3	8.3257E+01	8.3871E-07	9.9268E+07
K	0.0037846	0.0007620	0.0024130	0.4821	117	2	74	3	8.2025E+01	1.8387E-06	4.4610E+07
K	0.0034798	0.0007747	0.0016383	0.3035	117	2	74	3	1.1283E+02	1.2692E-06	8.8902E+07
K	0.0030226	0.0006604	0.0012700	0.2837	117	2	74	3	8.3257E+01	8.3871E-07	9.9268E+07
K	0.0025845	0.0004572	0.0017780	0.3394	117	2	74	3	9.0098E+01	8.1290E-07	1.1084E+08
K	0.0029464	0.0006731	0.0016256	0.3496	117	2	74	3	1.1131E+02	1.0942E-06	1.0173E+08
K	0.0047498	0.0008255	0.0018161	0.4352	117	2	74	3	8.8977E+01	1.4992E-06	5.9350E+07
K	0.0029464	0.0006223	0.0013716	0.3787	117	2	74	3	9.4231E+01	8.5355E-07	1.1040E+08
K	0.0029464	0.0006731	0.0016256	0.3496	117	2	74	3	1.1131E+02	1.0942E-06	1.0173E+08
K	0.0029464	0.0006223	0.0013716	0.3787	117	2	74	3	9.4231E+01	8.5355E-07	1.1040E+08
K	0.0036576	0.0005461	0.0018415	0.2496	117	2	146	4	1.0435E+02	1.0056E-06	1.0376E+08
K	0.0028575	0.0004826	0.0015494	0.1228	117	2	146	4	9.1508E+01	7.4774E-07	1.2238E+08
K	0.0034798	0.0008382	0.0019558	0.1491	117	2	146	4	1.1889E+02	1.6394E-06	7.2521E+07
K	0.0029591	0.0005842	0.0013970	0.1496	117	2	146	4	7.8889E+01	8.1613E-07	9.6662E+07
K	0.0036576	0.0005461	0.0018415	0.2496	117	2	146	4	1.0435E+02	1.0056E-06	1.0376E+08
K	0.0028575	0.0004826	0.0015494	0.1228	117	2	146	4	9.1508E+01	7.4774E-07	1.2238E+08
K	0.0040005	0.0010033	0.0016002	0.3339	117	2	146	4	1.3757E+02	1.6055E-06	8.5685E+07
K	0.0046609	0.0013462	0.0020955	0.2470	117	2	146	4	1.6905E+02	2.8210E-06	5.9926E+07
K	0.0039751	0.0006350	0.0018669	0.1009	117	2	146	4	9.9408E+01	1.1855E-06	8.3855E+07
K	0.0034290	0.0006985	0.0016383	0.2336	117	2	146	4	1.1163E+02	1.1444E-06	9.7546E+07
K	0.0040005	0.0010033	0.0016002	0.3339	117	2	146	4	1.3757E+02	1.6055E-06	8.5685E+07
K	0.0038481	0.0007747	0.0017526	0.1119	117	2	242	5	1.6926E+02	1.3577E-06	1.2466E+08
K	.	0.0005842	0.0015240	0.1023	117	2	242	5	1.0427E+02	8.9032E-07	1.1712E+08
K	0.0034163	0.0005842	0.0020955	0.1611	117	2	242	5	1.1475E+02	1.2242E-06	9.3732E+07

K	0.0029210	0.0004064	0.0016764	0.1146	117	2	242	5	6.5518E+01	6.8129E-07	9.6167E+07
K	0.0029591	0.0006604	0.0013081	0.1081	117	2	242	5	9.6388E+01	8.6387E-07	1.1158E+08
K	0.0028702	0.0008382	0.0009525	0.0982	117	2	242	5	5.1697E+01	7.9839E-07	6.4752E+07
K	0.0033020	0.0005969	0.0009525	0.1006	117	2	242	5	6.7239E+01	5.6855E-07	1.1826E+08
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K	0.0038862	0.0010541	0.0020574	0.5800	131	3	2	1	1.3212E+02	2.1687E-06	6.0921E+07
K	0.0051435	0.0011303	0.0010795	0.5120	131	3	2	1	4.6048E+01	1.2202E-06	3.7739E+07
K	0.0052197	0.0012319	0.0028194	0.5120	131	3	2	1	2.0419E+02	3.4732E-06	5.8789E+07
K	0.0048006	0.0008128	0.0022733	0.5955	131	3	2	1	1.3878E+02	1.8477E-06	7.5110E+07
K	0.0030480	0.0013716	0.0013716	0.6185	131	3	2	1	7.8182E+01	1.8813E-06	4.1557E+07
K	0.0036322	0.0015367	0.0015367	0.6006	131	3	2	1	7.1371E+01	2.3615E-06	3.0224E+07
K	0.0030480	0.0015240	0.0006731	0.6280	131	3	2	1	8.2901E+01	1.0258E-06	8.0816E+07
K	0.0037338	0.0006858	0.0012954	0.5804	131	3	2	1	6.8662E+01	8.8839E-07	7.7289E+07
K	0.0037973	0.0006985	0.0018288	0.6374	131	3	2	1	9.3105E+01	1.2774E-06	7.2886E+07
K	0.0029591	0.0005080	0.0012827	0.6646	131	3	2	1	4.8072E+01	6.5161E-07	7.3774E+07
K	0.0038354	0.0008636	0.0020701	0.6608	131	3	2	1	1.2353E+02	1.7877E-06	6.9099E+07
K	0.0038481	0.0007747	0.0017018	0.4819	131	3	26	2	7.3026E+01	1.3184E-06	5.5391E+07
K	0.0030480	0.0007112	0.0013462	0.4530	131	3	26	2	7.2012E+01	9.5742E-07	7.5215E+07
K	0.0034544	0.0006350	0.0014097	0.4685	131	3	26	2	4.8623E+01	8.9516E-07	5.4318E+07
K	0.0040005	0.0005461	0.0021844	0.4446	131	3	26	2	1.1885E+02	1.1929E-06	9.9629E+07
K	0.0029972	0.0006731	0.0010287	0.4796	131	3	26	2	6.5638E+01	6.9242E-07	9.4795E+07
K	0.0029972	0.0007112	0.0014859	0.5253	131	3	26	2	1.0133E+02	1.0568E-06	9.5886E+07
K	0.0042799	0.0008255	0.0019177	0.4988	131	3	26	2	1.4152E+02	1.5831E-06	8.9399E+07
K	0.0039370	0.0007874	0.0016002	0.5663	131	3	26	2	1.2025E+02	1.2600E-06	9.5435E+07
K	0.0032893	0.0014478	0.0005715	0.5248	131	3	26	2	7.8075E+01	8.2742E-07	9.4360E+07
K	0.0044577	0.0007366	0.0024257	0.5384	131	3	26	2	1.4900E+02	1.7868E-06	8.3391E+07
K	0.0052070	0.0012319	0.0029464	0.4846	131	3	74	3	2.4052E+02	3.6297E-06	6.6265E+07
K	0.0034163	0.0009144	0.0023622	0.3295	131	3	74	3	1.3587E+02	2.1600E-06	6.2905E+07
K	0.0052070	0.0007874	0.0021971	0.3767	131	3	74	3	1.4598E+02	1.7300E-06	8.4380E+07
K	0.0044704	0.0009271	0.0022352	0.4568	131	3	74	3	1.8005E+02	2.0723E-06	8.6886E+07
K	0.0034671	0.0006858	0.0017399	0.4155	131	3	74	3	1.2314E+02	1.1932E-06	1.0320E+08
K	0.0035179	0.0006223	0.0015621	0.2655	131	3	74	3	7.7261E+01	9.7210E-07	7.9479E+07
K	0.0039370	0.0009017	0.0020447	0.4774	131	3	74	3	1.1815E+02	1.8437E-06	6.4082E+07
K	0.0044577	0.0008890	0.0017145	0.4541	131	3	74	3	1.2176E+02	1.5242E-06	7.9885E+07
K	0.0041656	0.0004699	0.0014859	0.1668	131	3	146	4	9.2692E+01	6.9822E-07	1.3275E+08
K	0.0037084	0.0006985	0.0007366	0.2307	131	3	146	4	4.8441E+01	5.1452E-07	9.4149E+07
K	0.0032258	0.0007874	0.0010668	0.1758	131	3	146	4	9.7451E+01	8.4000E-07	1.1601E+08
K	0.0041402	0.0007112	0.0019939	0.0851	131	3	146	4	1.6400E+02	1.4181E-06	1.1565E+08
K	0.0030226	0.0004572	0.0011938	0.1523	131	3	146	4	5.1995E+01	5.4581E-07	9.5263E+07
K	0.0043942	0.0008255	0.0011557	0.0811	131	3	146	4	1.1551E+02	9.5403E-07	1.2108E+08
K	0.0029845	0.0005715	0.0015367	0.1107	131	3	146	4	8.5761E+01	8.7822E-07	9.7653E+07
K	0.0039497	0.0006223	0.0013716	0.1758	131	3	146	4	.	8.5355E-07	.
K	0.0046101	0.0008636	0.0015367	0.1007	131	3	242	5	1.0790E+02	1.3271E-06	8.1309E+07
K	0.0046228	0.0009017	0.0010160	0.0988	131	3	242	5	9.6508E+01	9.1613E-07	1.0534E+08
K	0.0029464	0.0006604	0.0014097	0.1620	131	3	242	5	1.0532E+02	9.3097E-07	1.1313E+08
K	0.0034798	0.0007366	0.0019177	0.1001	131	3	242	5	1.9172E+02	1.4126E-06	1.3572E+08
K	0.0028321	0.0002540	0.0013335	0.1077	131	3	242	5	5.4250E+01	3.3871E-07	1.6017E+08
K	0.0030734	0.0005080	0.0015875	0.0988	131	3	242	5	9.5458E+01	8.0645E-07	1.1837E+08
K	0.0028702	0.0005207	0.0010287	0.0974	131	3	242	5	7.5691E+01	5.3564E-07	1.4131E+08
K	0.0024257	0.0004191	0.0014605	0.1096	131	3	242	5	8.0615E+01	6.1210E-07	1.3170E+08
K	0.0028702	0.0007747	0.0018034	0.6305	159	5	2	1	8.8208E+01	1.3971E-06	6.3137E+07

K	0.0031877	0.0007620	0.0012446	0.6551	159	5	2	1	7.5824E+01	9.4839E-07	7.9951E+07
K	0.0037084	0.0008128	0.0013081	0.6247	159	5	2	1	4.7485E+01	1.0632E-06	4.4661E+07
K	0.0040894	0.0008382	0.0012192	0.6338	159	5	2	1	7.8488E+01	1.0219E-06	7.6804E+07
K	0.0036068	0.0007112	0.0020574	0.6862	159	5	2	1	8.8848E+01	1.4632E-06	6.0721E+07
K	0.0037338	0.0007493	0.0016002	0.7053	159	5	2	1	7.8431E+01	1.1990E-06	6.5412E+07
K	0.0036322	0.0006223	0.0009652	0.7554	159	5	2	1	6.4784E+01	6.0064E-07	1.0786E+08
K	0.0032385	0.0006731	0.0009652	0.6612	159	5	2	1	5.0678E+01	6.4968E-07	7.8006E+07
K	0.0029718	0.0007747	0.0012446	0.6447	159	5	2	1	8.7621E+01	9.6419E-07	9.0875E+07
K	0.0036195	0.0009144	0.0016764	0.6297	159	5	2	1	1.0333E+02	1.5329E-06	6.7409E+07
K	0.0036830	0.0006096	0.0014097	0.5241	159	5	26	2	.	8.5935E-07	.
K	0.0030353	0.0004064	0.0016891	0.5000	159	5	26	2	8.0730E+01	6.8645E-07	1.1761E+08
K	0.0032893	0.0005842	0.0014986	0.4424	159	5	26	2	7.9311E+01	8.7548E-07	9.0592E+07
K	0.0034163	0.0007874	0.0015875	0.4931	159	5	26	2	1.0576E+02	1.2500E-06	8.4608E+07
K	0.0028067	0.0004826	0.0017653	0.4545	159	5	26	2	9.8319E+01	8.5193E-07	1.1541E+08
K	0.0041402	0.0006985	0.0019558	0.5305	159	5	26	2	1.2189E+02	1.3661E-06	8.9223E+07
K	0.0037592	0.0007493	0.0012065	0.6351	159	5	26	2	7.7287E+01	9.0403E-07	8.5492E+07
K	0.0030734	0.0007239	0.0016764	0.4583	159	5	26	2	9.9168E+01	1.2136E-06	8.1718E+07
K	0.0032766	0.0007874	0.0012065	0.4599	159	5	26	2	7.8898E+01	9.5000E-07	8.3050E+07
K	0.0043434	0.0007239	0.0017907	0.5113	159	5	26	2	9.4186E+01	1.2963E-06	7.2658E+07
K	0.0043434	0.0007874	0.0022225	0.2910	159	5	74	3	2.0012E+02	1.7500E-06	1.1435E+08
K	0.0048641	0.0006985	0.0027305	0.2622	159	5	74	3	1.8379E+02	1.9073E-06	9.6364E+07
K	0.0040386	0.0006350	0.0013716	0.2621	159	5	74	3	9.2847E+01	8.7097E-07	1.0660E+08
K	0.0040005	0.0007366	0.0015748	0.4133	159	5	74	3	1.0537E+02	1.1600E-06	9.0835E+07
K	0.0025273	0.0005207	0.0012700	0.2287	159	5	74	3	5.0736E+01	6.6129E-07	7.6723E+07
K	0.0030607	0.0005715	0.0012954	0.2515	159	5	74	3	8.0108E+01	7.4032E-07	1.0821E+08
K	0.0037846	0.0008001	0.0018288	0.2304	159	5	74	3	1.3672E+02	1.4632E-06	9.3434E+07
K	0.0033528	0.0005461	0.0010668	0.2317	159	5	74	3	4.9313E+01	5.8258E-07	8.4646E+07
K	0.0027178	0.0006477	0.0009779	0.3183	159	5	74	3	7.4476E+01	6.3339E-07	1.1758E+08
K	0.0027813	0.0005588	0.0018161	0.1436	159	5	74	3	9.1584E+01	1.0148E-06	9.0245E+07
K	0.0028829	0.0006350	0.0012573	0.2226	159	5	146	4	9.9164E+01	7.9839E-07	1.2421E+08
K	0.0034163	0.0007620	0.0014605	0.2859	159	5	146	4	1.1973E+02	1.1129E-06	1.0758E+08
K	0.0028956	0.0006350	0.0013081	0.2994	159	5	146	4	8.4391E+01	8.3064E-07	1.0160E+08
K	0.0031750	0.0007874	0.0011811	0.1888	159	5	146	4	1.0579E+02	9.3000E-07	1.1375E+08
K	0.0030353	0.0006477	0.0016891	0.1674	159	5	146	4	9.5467E+01	1.0940E-06	8.7262E+07
K	0.0035306	0.0006731	0.0016002	0.3211	159	5	146	4	1.1994E+02	1.0771E-06	1.1135E+08
K	0.0045339	0.0008001	0.0021844	0.2395	159	5	146	4	1.8095E+02	1.7477E-06	1.0354E+08
K	0.0041148	0.0007493	0.0010668	0.2300	159	5	146	4	8.5392E+01	7.9935E-07	1.0683E+08
K	0.0037211	0.0006223	0.0022987	0.1993	159	5	146	4	1.0888E+02	1.4305E-06	7.6116E+07
K	0.0040005	0.0007493	0.0022860	0.1197	159	5	146	4	2.0229E+02	1.7129E-06	1.1810E+08
K	0.0028702	0.0005461	0.0012446	0.1204	159	5	174		5.9904E+01	6.7968E-07	8.8136E+07
K	0.0028067	0.0006477	0.0013335	0.1054	159	5	174		1.3367E+02	8.6371E-07	1.5476E+08
K	0.0024257	0.0005080	0.0017399	0.1041	159	5	174		9.2945E+01	8.8387E-07	1.0516E+08
K	0.0028042	0.0005969	0.0017907	0.1727	159	5	174		1.2677E+02	1.0689E-06	1.1861E+08
K	0.0031115	0.0006350	0.0011049	0.2865	159	5	174		8.4961E+01	7.0161E-07	1.2109E+08
K	0.0032131	0.0006096	0.0016637	0.2274	159	5	174		9.7051E+01	1.0142E-06	9.5693E+07
K	0.0039243	0.0006604	0.0016002	0.1529	159	5	174		8.3986E+01	1.0568E-06	7.9475E+07
K	0.0037084	0.0006985	0.0021082	0.2789	159	5	174		.	1.4726E-06	.
K	0.0030353	0.0006096	0.0019939	0.0998	159	5	174		9.6557E+01	1.2155E-06	7.9439E+07
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K	0.0037338	0.0008001	0.0022352	0.5415	145	4	2	1	1.4609E+02	1.7884E-06	8.1687E+07
K	0.0044704	0.0008382	0.0028702	0.5276	145	4	2	1	1.4313E+02	2.4058E-06	5.9492E+07
K	0.0047117	0.0009398	0.0030734	0.5472	145	4	2	1	2.0950E+02	2.8884E-06	7.2532E+07

K	0.0043815	0.0008763	0.0022098	0.5897	145	4	2	1	1.0916E+02	1.9365E-06	5.6371E+07
K	0.0035814	0.0008509	0.0021082	0.5615	145	4	2	1	9.0000E+01	1.7939E-06	5.0171E+07
K	0.0038227	0.0007112	0.0026035	0.6612	145	4	2	1	1.4074E+02	1.8516E-06	7.6010E+07
K	0.0034671	0.0008255	0.0015367	0.6208	145	4	2	1	1.0215E+02	1.2686E-06	8.0528E+07
K	0.0037084	0.0007366	0.0013462	0.5976	145	4	2	1	7.4734E+01	9.9161E-07	7.5366E+07
K	0.0047244	0.0009017	0.0021590	0.5770	145	4	2	1	1.2725E+02	1.9468E-06	6.5364E+07
K	0.0031369	0.0007620	0.0013081	0.5849	145	4	2	1	8.6869E+01	9.9677E-07	8.7150E+07
K	0.0039370	0.0006350	0.0015113	0.5335	145	4	26	2	7.7581E+01	9.5968E-07	8.0841E+07
K	0.0035052	0.0006350	0.0017526	0.4332	145	4	26	2	1.0672E+02	1.1129E-06	9.5895E+07
K	0.0039751	0.0007366	0.0016764	0.5101	145	4	26	2	1.3792E+02	1.2348E-06	1.1169E+08
K	0.0031369	0.0005461	0.0013081	0.4596	145	4	26	2	7.6500E+01	7.1435E-07	1.0709E+08
K	0.0029845	0.0004572	0.0011938	0.4754	145	4	26	2	7.0384E+01	5.4581E-07	1.2895E+08
K	0.0041402	0.0006731	0.0014097	0.5012	145	4	26	2	8.8968E+01	9.4887E-07	9.3763E+07
K	0.0036957	0.0005715	0.0014986	0.4824	145	4	26	2	1.0496E+02	8.5645E-07	1.2255E+08
K	0.0028702	0.0005715	0.0016002	0.4538	145	4	26	2	8.1602E+01	9.1451E-07	8.9230E+07
K	0.0035052	0.0006350	0.0016764	0.4404	145	4	26	2	1.1278E+02	1.0645E-06	1.0594E+08
K	0.0037084	0.0007112	0.0020320	0.4683	145	4	26	2	1.3983E+02	1.4452E-06	9.6760E+07
K	0.0040894	0.0007747	0.0020828	0.3240	145	4	50	3	6.6527E+01	6.3749E-06	1.0436E+07
K	0.0036830	0.0006858	0.0018034	0.2736	145	4	50	3	7.5775E+01	4.7668E-06	1.5897E+07
K	0.0045466	0.0006731	0.0013208	0.3581	145	4	50	3	7.3876E+01	6.1230E-06	1.2065E+07
K	0.0034544	0.0007112	0.0016129	0.2801	145	4	50	3	1.1325E+02	5.0592E-06	2.2384E+07
K	0.0028829	0.0005080	0.0015113	0.2689	145	4	50	3	1.0068E+02	3.4695E-06	2.9019E+07
K	0.0033147	0.0007112	0.0012319	0.3211	145	4	50	3	1.0348E+02	5.8013E-06	1.7837E+07
K	0.0030734	0.0005207	0.0018034	0.2582	145	4	50	3	9.9075E+01	3.4151E-06	2.9011E+07
K	0.0044958	0.0006096	0.0012700	0.3050	145	4	50	3	7.3569E+01	4.7231E-06	1.5576E+07
K	0.0026670	0.0008509	0.0011430	0.3261	145	4	50	3	7.7875E+01	7.0469E-06	1.1051E+07
K	0.0035560	0.0009271	0.0019812	0.4749	145	4	50	3	1.0416E+02	1.1183E-05	9.3142E+06
K	0.0032766	0.0004953	0.0016637	0.1053	145	4	170	4	8.2327E+01	8.2403E-07	9.9908E+07
K	0.0033274	0.0006604	0.0017907	0.0887	145	4	170	4	7.4921E+01	1.1826E-06	6.3354E+07
K	0.0046609	0.0006731	0.0018542	0.1272	145	4	170	4	1.3292E+02	1.2481E-06	1.0650E+08
K	0.0036703	0.0006477	0.0011938	0.0939	145	4	170	4	1.0499E+02	7.7322E-07	1.3578E+08
K	0.0032512	0.0005969	0.0014732	0.1346	145	4	170	4	1.0445E+02	8.7935E-07	1.1878E+08
K	0.0031115	0.0005842	0.0017399	0.1288	145	4	170	4	1.0811E+02	1.0165E-06	1.0636E+08
K	0.0032131	0.0004826	0.0009906	0.1094	145	4	170	4	6.0584E+01	4.7806E-07	1.2673E+08
K	0.0026289	0.0004572	0.0022860	0.1182	145	4	170	4	7.1180E+01	1.0452E-06	6.8105E+07

Shear test data for Alamo

V	Dia (m)	Thick (m)	MC	Mhrs	Mds	Mcl	Hah	Hcl	Force (N)	Area (m^2)	SS(N/m^2)
A	0.0036830	0.0007620	0.5267	2304	96	6	6	1	4.1823E+02	6.9890E-06	2.9920E+07
A	0.0026670	0.0006350	0.5312	2304	96	6	6	1	2.8990E+02	4.0516E-06	3.5776E+07
A	0.0030480	0.0008890	0.5939	2304	96	6	6	1	1.6921E+02	6.0268E-06	1.4039E+07
A	0.0020320	0.0005080	0.5862	2304	96	6	6	1	1.3561E+02	2.4310E-06	2.7892E+07
A	0.0035306	0.0005080	0.6303	2304	96	6	6	1	1.2623E+02	4.8214E-06	1.3091E+07
A	0.0025400	0.0004826	0.6025	2304	96	6	6	1	1.8251E+02	3.1177E-06	2.9271E+07
A	0.0035560	0.0007366	0.5800	2304	96	6	6	1	2.6508E+02	6.5211E-06	2.0325E+07
A	0.0024892	0.0005588	0.4942	2304	96	6	6	1	2.7058E+02	3.3871E-06	3.9942E+07
A	0.0038862	0.0006350	0.5247	2304	96	6	30	2	2.8870E+02	6.4826E-06	2.2268E+07
A	0.0035814	0.0007620	0.5041	2304	96	6	30	2	3.0259E+02	6.7459E-06	2.2428E+07
A	0.0030480	0.0004572	0.5566	2304	96	6	30	2	1.5585E+02	3.7194E-06	2.0951E+07

A	0.0036322	0.0005842	0.5403	2304	96	6	30	2	2.3283E+02	5.5912E-06	2.0821E+07
A	0.0025400	0.0006096	0.5017	2304	96	6	30	2	2.0389E+02	3.6951E-06	2.7590E+07
A	0.0031750	0.0005334	0.5701	2304	96	6	30	2	2.0653E+02	4.4244E-06	2.3340E+07
A	0.0026670	0.0004318	0.5136	2304	96	6	30	2	1.8309E+02	3.0306E-06	3.0207E+07
A	0.0027940	0.0005588	0.4765	2304	96	6	30	2	2.6216E+02	3.9220E-06	3.3422E+07
A	0.0038100	0.0007112	0.6780	2304	96	6	78	3	4.0431E+02	6.9201E-06	2.9212E+07
A	0.0025908	0.0005588	0.2710	2304	96	6	78	3	1.8025E+02	3.5654E-06	2.5278E+07
A	0.0038100	0.0008890	0.5750	2304	96	6	78	3	2.5562E+02	8.1539E-06	1.5675E+07
A	0.0035052	0.0006604	0.4170	2304	96	6	78	3	2.0354E+02	5.8991E-06	1.7251E+07
A	0.0030480	0.0004064	0.1650	2304	96	6	78	3	1.1834E+02	7.2929E-06	8.1131E+06
A	0.0030480	0.0005080	0.3800	2304	96	6	78	3	1.9773E+02	7.2929E-06	1.3556E+07
A	0.0035560	0.0006604	0.3520	2304	96	6	78	3	2.5961E+02	9.9264E-06	1.3076E+07
A	0.0034290	0.0003810	0.2550	2304	96	6	78	3	1.4248E+02	9.2301E-06	7.7180E+06
A	0.0035306	0.0005080	0.2898	2304	96	6	150	4	2.5985E+02	4.8214E-06	2.6948E+07
A	0.0032512	0.0005080	0.1513	2304	96	6	150	4	1.3614E+02	4.3757E-06	1.5556E+07
A	0.0029210	0.0006350	0.3044	2304	96	6	150	4	1.6942E+02	4.5581E-06	1.8585E+07
A	0.0030988	0.0005588	0.4636	2304	96	6	150	4	2.2507E+02	4.4568E-06	2.5250E+07
A	0.0029210	0.0005080	0.2674	2304	96	6	150	4	1.1334E+02	3.8490E-06	1.4723E+07
A	0.0036830	0.0007620	0.3983	2304	96	6	150	4	3.1530E+02	6.9890E-06	2.2557E+07
A	0.0037084	0.0007620	0.3419	2304	96	6	150	4	2.9095E+02	7.0498E-06	2.0635E+07
A	0.0038354	0.0006350	0.4180	2304	96	6	150	4	2.5631E+02	6.3813E-06	2.0083E+07
A	0.0031750	0.0005588	0.0896	2304	96	6	390	6	2.4967E+02	4.5905E-06	2.7194E+07
A	0.0029464	0.0006858	0.0878	2304	96	6	390	6	1.7396E+02	4.8680E-06	1.7868E+07
A	0.0033020	0.0005588	0.0906	2304	96	6	390	6	2.8496E+02	4.8133E-06	2.9601E+07
A	0.0034798	0.0007874	0.0885	2304	96	6	390	6	4.8244E+02	6.6568E-06	3.6237E+07
A	0.0033528	0.0003810	0.0866	2304	96	6	390	6	2.1605E+02	3.5553E-06	3.0384E+07
A	0.0033528	0.0005080	0.0977	2304	96	6	390	6	1.6703E+02	4.5378E-06	1.8404E+07
A	0.0031750	0.0005588	0.0846	2304	96	6	390	6	1.9122E+02	4.5905E-06	2.0828E+07
A	0.0030226	0.0005588	0.0935	2304	96	6	390	6	2.2450E+02	4.3231E-06	2.5965E+07
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A	0.0043180	0.0005588	0.3994	2640	110	7	6	1	4.4242E+02	6.5960E-06	3.3537E+07
A	0.0043180	0.0005334	0.5372	2640	110	7	6	1	3.7763E+02	6.3387E-06	2.9787E+07
A	0.0038100	0.0006350	0.5838	2640	110	7	6	1	3.4178E+02	6.3306E-06	2.6994E+07
A	0.0040640	0.0004572	0.5539	2640	110	7	6	1	2.3426E+02	5.1780E-06	2.2620E+07
A	0.0041402	0.0005842	0.5168	2640	110	7	6	1	3.7016E+02	6.5231E-06	2.8373E+07
A	0.0043180	0.0007620	0.4538	2640	110	7	6	1	5.7039E+02	8.5084E-06	3.3519E+07
A	0.0038100	0.0007620	0.5255	2640	110	7	30	2	3.8799E+02	7.2929E-06	2.6601E+07
A	0.0038100	0.0007620	0.4031	2640	110	7	30	2	3.2389E+02	7.2929E-06	2.2206E+07
A	0.0043180	0.0008890	0.4585	2640	110	7	30	2	2.9634E+02	9.5719E-06	1.5480E+07
A	0.0034290	0.0005334	0.4365	2640	110	7	30	2	2.5674E+02	4.8498E-06	2.6469E+07
A	0.0036830	0.0006604	0.3895	2640	110	7	30	2	4.7987E+02	6.2678E-06	3.8281E+07
A	0.0029210	0.0007366	0.4986	2640	110	7	30	2	2.6964E+02	5.0524E-06	2.6685E+07
A	0.0034290	0.0006350	0.3638	2640	110	7	78	3	2.2812E+02	5.5710E-06	2.0474E+07
A	0.0038100	0.0007620	0.2861	2640	110	7	78	3	4.6865E+02	7.2929E-06	3.2131E+07
A	0.0035560	0.0005588	0.3695	2640	110	7	78	3	3.6395E+02	5.2590E-06	3.4603E+07
A	0.0031750	0.0005588	0.3239	2640	110	7	78	3	1.5490E+02	4.5905E-06	1.6872E+07
A	0.0034290	0.0006350	0.2984	2640	110	7	78	3	3.1844E+02	5.5710E-06	2.8580E+07
A	0.0028194	0.0006350	0.3853	2640	110	7	78	3	3.1219E+02	4.3555E-06	3.5839E+07
A	0.0031750	0.0006350	0.3831	2640	110	7	78	3	3.5331E+02	5.0645E-06	3.4881E+07
A	0.0035560	0.0003556	0.4494	2640	110	7	78	3	1.4637E+02	3.5735E-06	2.0480E+07
A	0.0033020	0.0006096	0.2200	2640	110	7	150	4	3.4183E+02	5.1536E-06	3.3164E+07
A	0.0039878	0.0006604	0.2153	2640	110	7	150	4	4.1159E+02	6.8999E-06	2.9826E+07

A	0.0027940	0.0005080	0.2500	2640	110	7	150	4	2.4487E+02	3.6464E-06	3.3576E+07
A	0.0029210	0.0005080	0.1802	2640	110	7	150	4	3.0749E+02	3.8490E-06	3.9943E+07
A	0.0038100	0.0007620	0.2578	2640	110	7	150	4	3.2584E+02	7.2929E-06	2.2340E+07
A	0.0040640	0.0007620	0.2862	2640	110	7	150	4	4.2273E+02	7.9006E-06	2.6753E+07
A	0.0033528	0.0007620	0.4099	2640	110	7	150	4	2.6052E+02	6.1990E-06	2.1013E+07
A	0.0025400	0.0003048	0.1331	2640	110	7	150	4	9.6593E+01	2.1393E-06	2.2576E+07
A	0.0019304	0.0003048	0.1694	2640	110	7	246	5	1.0819E+02	3.1116E-06	1.7385E+07
A	0.0021844	0.0003048	0.1299	2640	110	7	246	5	1.0486E+02	3.5978E-06	1.4573E+07
A	0.0025400	0.0003048	0.1246	2640	110	7	246	5	1.7102E+02	4.2785E-06	1.9987E+07
A	0.0024130	0.0002540	0.0971	2640	110	7	246	5	1.0505E+02	3.4439E-06	1.5252E+07
A	0.0027940	0.0005080	0.2193	2640	110	7	246	5	2.2977E+02	7.2929E-06	1.5753E+07
A	0.0027432	0.0005080	0.2207	2640	110	7	246	5	2.1326E+02	7.1308E-06	1.4954E+07
A	0.0033020	0.0007620	0.1136	2640	110	7	246	5	2.8473E+02	1.2155E-05	1.1713E+07
A	0.0033020	0.0005461	0.1506	2640	110	7	246	5	2.1810E+02	9.4514E-06	1.1538E+07
A	0.0035560	0.0006858	0.1100	2640	110	7	246	5	2.8763E+02	1.2361E-05	1.1634E+07
A	0.0030480	0.0004572	0.1272	2640	110	7	246	5	2.0693E+02	7.4388E-06	1.3909E+07
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A	0.0036068	0.0011049	0.5363	2976	124	8	6	1	2.9520E+02	8.6801E-06	1.7005E+07
A	0.0031750	0.0009525	0.4917	2976	124	8	6	1	2.7706E+02	6.6472E-06	2.0841E+07
A	0.0036957	0.0013335	0.4389	2976	124	8	6	1	3.1178E+02	9.8910E-06	1.5761E+07
A	0.0030480	0.0009906	0.4278	2976	124	8	6	1	3.0342E+02	6.3995E-06	2.3707E+07
A	0.0041402	0.0008509	0.6241	2976	124	8	6	1	2.3809E+02	8.7884E-06	1.3546E+07
A	0.0038354	0.0009271	0.5733	2976	124	8	6	1	2.6476E+02	8.4663E-06	1.5636E+07
A	0.0034925	0.0009271	0.5371	2976	124	8	6	1	2.9512E+02	7.4681E-06	1.9758E+07
A	0.0035560	0.0007112	0.6401	2976	124	8	6	1	1.3554E+02	6.3529E-06	1.0668E+07
A	0.0047498	0.0010160	0.5484	2976	124	8	6	1	3.2989E+02	1.1912E-05	1.3847E+07
A	0.0034544	0.0005715	0.4879	2976	124	8	30	2	2.2785E+02	5.1734E-06	2.2022E+07
A	0.0032766	0.0009144	0.4130	2976	124	8	30	2	2.7746E+02	6.7824E-06	2.0455E+07
A	0.0036068	0.0008128	0.3905	2976	124	8	30	2	2.1368E+02	7.1308E-06	1.4983E+07
A	0.0031242	0.0006350	0.4710	2976	124	8	30	2	1.9306E+02	4.9632E-06	1.9449E+07
A	0.0035497	0.0006096	0.4476	2976	124	8	30	2	1.7019E+02	5.6277E-06	1.5121E+07
A	0.0034100	0.0005588	0.4782	2976	124	8	30	2	1.3630E+02	5.0027E-06	1.3622E+07
A	0.0037783	0.0008890	0.3796	2976	124	8	30	2	2.9056E+02	8.0652E-06	1.8013E+07
A	0.0042545	0.0008001	0.4469	2976	124	8	30	2	2.6225E+02	8.6785E-06	1.5109E+07
A	0.0044450	0.0008382	0.4416	2976	124	8	78	3	3.2721E+02	9.4929E-06	1.7234E+07
A	0.0041148	0.0007620	0.3653	2976	124	8	78	3	1.9556E+02	8.0222E-06	1.2188E+07
A	0.0034925	0.0006985	0.3377	2976	124	8	78	3	1.9648E+02	6.1281E-06	1.6031E+07
A	0.0033782	0.0008382	0.2522	2976	124	8	78	3	2.8770E+02	6.6852E-06	2.1518E+07
A	0.0029845	0.0007747	0.2690	2976	124	8	78	3	2.4330E+02	5.3755E-06	2.2631E+07
A	0.0032766	0.0009068	0.3776	2976	124	8	78	3	2.6838E+02	6.7476E-06	1.9887E+07
A	0.0036576	0.0006477	0.3804	2976	124	8	78	3	1.3757E+02	6.1215E-06	1.1236E+07
A	0.0039878	0.0006350	0.3908	2976	124	8	78	3	1.7429E+02	6.6852E-06	1.3036E+07
A	0.0031242	0.0005842	0.1057	2976	124	8	150	4	1.4087E+02	7.6621E-06	9.1924E+06
A	0.0029210	0.0008890	0.1421	2976	124	8	150	4	2.8962E+02	6.6978E-06	2.1621E+07
A	0.0034798	0.0007874	0.0933	2976	124	8	150	4	4.2949E+02	9.5056E-06	2.2592E+07
A	0.0028194	0.0007620	0.1218	2976	124	8	150	4	2.7177E+02	6.2400E-06	2.1777E+07
A	0.0044704	0.0011659	0.1552	2976	124	8	150	4	3.2104E+02	1.5688E-05	1.0232E+07
A	0.0039878	0.0009093	0.3157	2976	124	8	150	4	4.3846E+02	1.2484E-05	1.7562E+07
A	0.0033274	0.0007239	0.2123	2976	124	8	150	4	2.7107E+02	8.6912E-06	1.5594E+07
A	0.0032512	0.0006350	0.1724	2976	124	8	150	4	1.1664E+02	8.2977E-06	7.0285E+06
A	0.0030226	0.0005969	0.0994	2976	124	8	246	5	1.2636E+02	4.5464E-06	1.3897E+07
A	0.0025527	0.0006985	0.1056	2976	124	8	246	5	1.8674E+02	4.0668E-06	2.2960E+07

A	0.0028575	0.0005715	0.0918	2976	124	8	246	5	9.4111E+01	4.1023E-06	1.1471E+07
A	0.0026797	0.0005842	0.1013	2976	124	8	246	5	1.7057E+02	3.8440E-06	2.2186E+07
A	0.0038989	0.0009068	0.0932	2976	124	8	246	5	3.1661E+02	8.5194E-06	1.8582E+07
A	0.0035941	0.0008001	0.0980	2976	124	8	246	5	3.0523E+02	7.0194E-06	2.1742E+07
A	0.0030099	0.0006731	0.0998	2976	124	8	246	5	1.8810E+02	4.9389E-06	1.9043E+07
A	0.0035179	0.0006223	0.0920	2976	124	8	246	5	1.8522E+02	5.6581E-06	1.6368E+07
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A	0.0035306	0.0006477	0.4118	3312	138	9	6	1	3.1551E+02	5.8632E-06	2.6906E+07
A	0.0034290	0.0006731	0.6547	3312	138	9	6	1	1.4464E+02	5.8247E-06	1.2416E+07
A	0.0034163	0.0008890	0.4672	3312	138	9	6	1	3.6398E+02	7.0549E-06	2.5796E+07
A	0.0037211	0.0007874	0.5607	3312	138	9	6	1	3.4694E+02	7.2534E-06	2.3916E+07
A	0.0038481	0.0008890	0.3130	3312	138	9	6	1	3.2283E+02	8.2602E-06	1.9541E+07
A	0.0030480	0.0007620	0.5639	3312	138	9	6	1	2.0930E+02	5.4697E-06	1.9132E+07
A	0.0046990	0.0010160	0.5797	3312	138	9	6	1	2.8166E+02	1.1750E-05	1.1986E+07
A	0.0038608	0.0009144	0.4892	3312	138	9	6	1	4.1615E+02	8.4598E-06	2.4596E+07
A	0.0034417	0.0007620	0.5506	3312	138	9	6	1	2.2003E+02	6.4117E-06	1.7159E+07
A	0.0038862	0.0011557	0.5020	3312	138	9	6	1	3.5026E+02	9.9087E-06	1.7675E+07
A	0.0030353	0.0006604	0.4711	3312	138	9	30	2	1.7272E+02	4.9247E-06	1.7536E+07
A	0.0039624	0.0009525	0.4264	3312	138	9	30	2	4.3535E+02	9.0022E-06	2.4181E+07
A	0.0032131	0.0007112	0.4080	3312	138	9	30	2	3.2646E+02	5.5872E-06	2.9215E+07
A	0.0028067	0.0007874	0.4480	3312	138	9	30	2	1.4516E+02	4.9926E-06	1.4537E+07
A	0.0040513	0.0009652	0.3032	3312	138	9	30	2	6.7716E+02	9.3531E-06	3.6200E+07
A	0.0040005	0.0007112	0.5068	3312	138	9	30	2	2.0059E+02	7.3456E-06	1.3654E+07
A	0.0034544	0.0007366	0.5205	3312	138	9	30	2	1.6248E+02	6.2861E-06	1.2924E+07
A	0.0046609	0.0007874	0.4451	3312	138	9	30	2	3.0282E+02	9.5770E-06	1.5810E+07
A	0.0030480	0.0005334	0.4947	3312	138	9	30	2	1.0616E+02	4.2116E-06	1.2603E+07
A	0.0041402	0.0008255	0.4870	3312	138	9	30	2	2.6285E+02	8.5919E-06	1.5296E+07
A	0.0034671	0.0007874	0.3472	3312	138	9	78	3	2.7533E+02	6.6254E-06	2.0778E+07
A	0.0031318	0.0006858	0.3997	3312	138	9	78	3	1.9323E+02	5.2673E-06	1.8342E+07
A	0.0036576	0.0009906	0.3871	3312	138	9	78	3	3.7787E+02	8.2957E-06	2.2775E+07
A	0.0046990	0.0007493	0.3310	3312	138	9	78	3	3.0936E+02	9.2929E-06	1.6645E+07
A	0.0036068	0.0008636	0.3793	3312	138	9	78	3	3.3940E+02	7.4388E-06	2.2813E+07
A	0.0030099	0.0006096	0.4198	3312	138	9	78	3	1.1551E+02	4.5945E-06	1.2571E+07
A	0.0032639	0.0006858	0.3940	3312	138	9	78	3	1.5064E+02	5.5517E-06	1.3567E+07
A	0.0039624	0.0009906	0.4277	3312	138	9	78	3	2.9420E+02	9.2437E-06	1.5913E+07
A	0.0038481	0.0010668	0.4043	3312	138	9	78	3	4.4782E+02	9.3167E-06	2.4033E+07
A	0.0036957	0.0007112	0.3958	3312	138	9	78	3	2.6552E+02	6.6649E-06	1.9919E+07
A	0.0023368	0.0005334	0.2105	3312	138	9	150	4	9.4004E+01	5.1000E-06	9.2161E+06
A	0.0019812	0.0005842	0.1399	3312	138	9	150	4	7.7274E+01	4.3514E-06	8.8792E+06
A	0.0033528	0.0007366	0.2030	3312	138	9	150	4	3.3735E+02	5.3198E-06	3.1707E+07
A	0.0028956	0.0007747	0.2517	3312	138	9	150	4	2.5566E+02	5.1592E-06	2.4777E+07
A	0.0022098	0.0005842	0.1417	3312	138	9	150	4	1.4189E+02	2.9820E-06	2.3791E+07
A	0.0021971	0.0004953	0.1435	3312	138	9	150	4	1.1555E+02	2.6467E-06	2.1829E+07
A	0.0034925	0.0007112	0.2098	3312	138	9	150	4	2.4436E+02	6.2111E-06	1.9671E+07
A	0.0030226	0.0007874	0.2054	3312	138	9	150	4	2.4123E+02	5.5264E-06	2.1826E+07
A	0.0033020	0.0005588	0.2678	3312	138	9	150	4	1.7646E+02	4.8133E-06	1.8330E+07
A	0.0030861	0.0006731	0.2403	3312	138	9	150	4	1.7536E+02	5.1000E-06	1.7192E+07
A	0.0028829	0.0006096	0.2041	3312	138	9	150	4	1.4395E+02	4.3514E-06	1.6540E+07
A	0.0032258	0.0006604	0.2735	3312	138	9	150	4	2.5473E+02	5.3198E-06	2.3942E+07
A	0.0022225	0.0006782	0.1279	3312	138	9	246	5	9.7029E+01	3.2886E-06	1.4752E+07
A	0.0030480	0.0007620	0.1183	3312	138	9	246	5	1.5470E+02	5.4697E-06	1.4142E+07
A	0.0025527	0.0005080	0.1051	3312	138	9	246	5	1.9991E+02	3.2615E-06	3.0646E+07

A	0.0023241	0.0007620	0.1295	3312	138	9	246	5	1.4877E+02	3.7376E-06	1.9901E+07
A	0.0046863	0.0008763	0.0853	3312	138	9	246	5	2.7412E+02	1.0484E-05	1.3074E+07
A	0.0044704	0.0008509	0.1135	3312	138	9	246	5	3.2259E+02	9.6707E-06	1.6679E+07
A	0.0035052	0.0008382	0.1623	3312	138	9	246	5	2.3668E+02	7.0194E-06	1.6859E+07
A	0.0036195	0.0007366	0.0930	3312	138	9	246	5	1.6405E+02	6.6679E-06	1.2301E+07
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A	0.0034925	0.0007112	0.5899	3648	152	10	6	1	2.0015E+02	6.2111E-06	1.6112E+07
A	0.0032131	0.0006985	0.6802	3648	152	10	6	1	1.3367E+02	5.5153E-06	1.2118E+07
A	0.0036957	0.0006731	0.6598	3648	152	10	6	1	1.4010E+02	6.3884E-06	1.0965E+07
A	0.0036068	0.0007874	0.6753	3648	152	10	6	1	1.1148E+02	6.9708E-06	7.9963E+06
A	0.0041656	0.0008255	0.5081	3648	152	10	6	1	3.2698E+02	8.6578E-06	1.8884E+07
A	0.0050292	0.0009652	0.4877	3648	152	10	6	1	4.4043E+02	1.2317E-05	1.7879E+07
A	0.0028956	0.0008763	0.5370	3648	152	10	6	1	2.8400E+02	5.5563E-06	2.5557E+07
A	0.0035052	0.0007620	0.5686	3648	152	10	6	1	3.2146E+02	6.5636E-06	2.4488E+07
A	0.0035052	0.0008763	0.5505	3648	152	10	6	1	3.2152E+02	7.2336E-06	2.2224E+07
A	0.0036449	0.0007620	0.4552	3648	152	10	30	2	2.3994E+02	6.8979E-06	1.7392E+07
A	0.0031877	0.0006223	0.4295	3648	152	10	30	2	2.2810E+02	5.0129E-06	2.2752E+07
A	0.0041402	0.0007620	0.3783	3648	152	10	30	2	4.7743E+02	8.0830E-06	2.9533E+07
A	0.0033909	0.0006858	0.4016	3648	152	10	30	2	3.0100E+02	5.8252E-06	2.5836E+07
A	0.0040513	0.0008001	0.2976	3648	152	10	30	2	3.6288E+02	8.1680E-06	2.2213E+07
A	0.0038989	0.0009271	0.3875	3648	152	10	30	2	4.6920E+02	8.6512E-06	2.7118E+07
A	0.0030353	0.0005715	0.5953	3648	152	10	30	2	1.2065E+02	4.4213E-06	1.3644E+07
A	0.0036449	0.0008636	0.5207	3648	152	10	30	2	3.6779E+02	7.5421E-06	2.4382E+07
A	0.0032004	0.0006604	0.4961	3648	152	10	30	2	2.0235E+02	5.2671E-06	1.9209E+07
A	0.0032258	0.0007366	0.4860	3648	152	10	30	2	1.5730E+02	5.7573E-06	1.3661E+07
A	0.0045466	0.0008001	0.4304	3648	152	10	78	3	3.9636E+02	9.4124E-06	2.1055E+07
A	0.0045212	0.0010033	0.2795	3648	152	10	78	3	5.0959E+02	1.1083E-05	2.2990E+07
A	0.0035814	0.0006350	0.2369	3648	152	10	78	3	2.8086E+02	5.8748E-06	2.3904E+07
A	0.0052324	0.0008001	0.3925	3648	152	10	78	3	4.8387E+02	1.1135E-05	2.1727E+07
A	0.0033147	0.0007493	0.3466	3648	152	10	78	3	1.7760E+02	6.0359E-06	1.4712E+07
A	0.0032639	0.0005334	0.3858	3648	152	10	78	3	1.7590E+02	4.5733E-06	1.9231E+07
A	0.0033655	0.0009017	0.3799	3648	152	10	78	3	2.6329E+02	6.9759E-06	1.8871E+07
A	0.0041656	0.0009144	0.4291	3648	152	10	78	3	4.0693E+02	9.3349E-06	2.1796E+07
A	0.0034925	0.0006223	0.1654	3648	152	10	150	4	2.7547E+02	5.6084E-06	2.4558E+07
A	0.0027178	0.0004318	0.2059	3648	152	10	150	4	1.3688E+02	3.0995E-06	2.2082E+07
A	0.0044196	0.0007366	0.1318	3648	152	10	150	4	2.9984E+02	8.5185E-06	1.7599E+07
A	0.0037211	0.0007112	0.1325	3648	152	10	150	4	2.8799E+02	6.7216E-06	2.1423E+07
A	0.0024638	0.0005588	0.1355	3648	152	10	150	4	2.0203E+02	3.3426E-06	3.0221E+07
A	0.0040767	0.0006731	0.1912	3648	152	10	150	4	3.7324E+02	7.1936E-06	2.5943E+07
A	0.0035306	0.0009144	0.1491	3648	152	10	150	4	3.4110E+02	7.5117E-06	2.2704E+07
A	0.0042672	0.0008128	0.2070	3648	152	10	150	4	3.2627E+02	8.8163E-06	1.8504E+07
A	0.0041148	0.0007874	0.1895	3648	152	10	150	4	2.0005E+02	8.2268E-06	1.2159E+07
A	0.0039624	0.0009017	0.2218	3648	152	10	150	4	3.1590E+02	8.6659E-06	1.8227E+07
A	0.0025654	0.0008636	0.0829	3648	152	10	222	5	2.1197E+02	4.6148E-06	2.2966E+07
A	0.0030861	0.0006096	0.0781	3648	152	10	222	5	1.6338E+02	4.7404E-06	1.7233E+07
A	0.0027432	0.0006096	0.0630	3648	152	10	222	5	1.3763E+02	4.0840E-06	1.6850E+07
A	0.0025400	0.0007112	0.0872	3648	152	10	222	5	1.7610E+02	4.0840E-06	2.1559E+07
A	0.0026543	0.0006223	0.0707	3648	152	10	222	5	1.2216E+02	3.9706E-06	1.5383E+07
A	0.0040005	0.0007620	0.0763	3648	152	10	222	5	3.1012E+02	7.7487E-06	2.0011E+07
A	0.0045720	0.0011430	0.1938	3648	152	10	222	5	4.6176E+02	1.2307E-05	1.8760E+07
A	0.0044831	0.0009144	0.2006	3648	152	10	222	5	4.1673E+02	1.0247E-05	2.0335E+07
A	0.0032766	0.0005588	0.0609	3648	152	10	222	5	1.4143E+02	4.7687E-06	1.4829E+07

A	0.0045339	0.0009906	0.1921	3648	152	10	222	5	5.3559E+02	1.1021E-05	2.4298E+07

Shear test data for Kanlow

V	Dia (m)	Thick (m)	MC	Mhrs	Mds	Mcl	HAH	Hcl	Force (N)	Area (m^2)	SS(N/m^2)
K	0.0038100	0.0006350	0.5938	2472	103	1	6	1	2.7687E+02	6.3306E-06	2.1868E+07
K	0.0036830	0.0006350	0.5070	2472	103	1	6	1	2.6773E+02	6.0774E-06	2.2027E+07
K	0.0043180	0.0008128	0.5806	2472	103	1	6	1	3.7109E+02	8.9459E-06	2.0741E+07
K	0.0038100	0.0005588	0.5494	2472	103	1	6	1	3.3828E+02	5.7047E-06	2.9650E+07
K	0.0037592	0.0005334	0.6558	2472	103	1	6	1	1.5255E+02	5.4028E-06	1.4117E+07
K	0.0040640	0.0005588	0.4021	2472	103	1	6	1	2.4845E+02	6.1503E-06	2.0198E+07
K	0.0034290	0.0005588	0.6450	2472	103	1	6	1	2.1712E+02	5.0361E-06	2.1556E+07
K	0.0034290	0.0007620	0.5734	2472	103	1	6	1	2.5531E+02	6.3813E-06	2.0005E+07
K	0.0030480	0.0005080	0.4858	2472	103	1	30	2	1.9170E+02	4.0516E-06	2.3658E+07
K	0.0040640	0.0007620	0.5445	2472	103	1	30	2	2.9863E+02	7.9006E-06	1.8899E+07
K	0.0050800	0.0009652.		2472	103	1	30	2	3.8275E+02	1.2471E-05	1.5346E+07
K	0.0030480	0.0004572	0.5027	2472	103	1	30	2	1.4785E+02	3.7194E-06	1.9876E+07
K	0.0033020	0.0006604	0.5528	2472	103	1	30	2	1.6938E+02	5.4778E-06	1.5461E+07
K	0.0035560	0.0005080	0.5792	2472	103	1	30	2	1.2547E+02	4.8619E-06	1.2903E+07
K	0.0048514	0.0008890.		2472	103	1	30	2	4.8570E+02	1.1061E-05	2.1956E+07
K	0.0036830	0.0006350	0.5460	2472	103	1	30	2	2.6700E+02	6.0774E-06	2.1967E+07
K	0.0041910	0.0004064	0.3763	2472	103	1	150	4	2.8925E+02	4.8295E-06	2.9946E+07
K	0.0046990	0.0007112	0.3866	2472	103	1	150	4	3.8421E+02	8.9054E-06	2.1572E+07
K	0.0033020	0.0005334	0.2309	2472	103	1	150	4	2.0213E+02	4.6371E-06	2.1795E+07
K	0.0031750	0.0005080	0.3409	2472	103	1	150	4	2.8380E+02	4.2542E-06	3.3355E+07
K	0.0045720	0.0006604	0.3532	2472	103	1	150	4	2.5368E+02	8.1113E-06	1.5637E+07
K	0.0050800	0.0007620	0.4102	2472	103	1	150	4	4.1433E+02	1.0332E-05	2.0052E+07
K	0.0036068	0.0005334	0.1816	2472	103	1	150	4	3.2029E+02	5.1476E-06	3.1111E+07
K	0.0035560	0.0006350	0.3634	2472	103	1	150	4	2.2424E+02	5.8242E-06	1.9251E+07
K	0.0040640	0.0003810	0.3120	2472	103	1	246	5	2.2114E+02	4.4061E-06	2.5094E+07
K	0.0029210	0.0003048	0.1662	2472	103	1	246	5	1.5434E+02	2.5039E-06	3.0821E+07
K	0.0029210	0.0002540	0.1308	2472	103	1	246	5	8.8110E+01	2.1271E-06	2.0711E+07
K	0.0029210	0.0003556	0.1858	2472	103	1	246	5	9.5485E+01	2.8645E-06	1.6667E+07
K	0.0029464	0.0005080	0.1134	2472	103	1	246	5	1.8557E+02	3.8895E-06	2.3855E+07
K	0.0036830	0.0005588	0.2500	2472	103	1	246	5	2.4919E+02	5.4818E-06	2.2729E+07
K	0.0028448	0.0004064	0.1786	2472	103	1	246	5	1.2664E+02	3.1116E-06	2.0350E+07
K	0.0024892	0.0002540	0.1422	2472	103	1	390	6	7.1456E+01	3.5654E-06	1.0021E+07
K	0.0030480	0.0005588	0.1179	2472	103	1	390	6	2.3204E+02	8.7353E-06	1.3282E+07
K	0.0027940	0.0003937	0.1224	2472	103	1	390	6	1.6934E+02	5.9346E-06	1.4267E+07
K	0.0022860	0.0005080	0.1289	2472	103	1	390	6	1.8475E+02	5.6316E-06	1.6403E+07
K	0.0043688	0.0006858	0.1095	2472	103	1	390	6	2.5569E+02	1.5862E-05	8.0597E+06
K	0.0034290	0.0005080	0.1220	2472	103	1	390	6	2.3491E+02	9.3187E-06	1.2604E+07
K	0.0034290	0.0005588	0.1088	2472	103	1	390	6	3.2527E+02	1.0072E-05	1.6147E+07
K	0.0033020	0.0004826	0.1170	2472	103	1	390	6	1.9182E+02	8.5448E-06	1.1224E+07
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K	0.0036195	0.0008890	0.6107	2808	117	2	6	1	2.0656E+02	7.6221E-06	1.3550E+07
K	0.0037084	0.0009906	0.5721	2808	117	2	6	1	4.0462E+02	8.4537E-06	2.3932E+07
K	0.0038481	0.0007874	0.5785	2808	117	2	6	1	3.1772E+02	7.5674E-06	2.0993E+07
K	0.0037465	0.0008001	0.6118	2808	117	2	6	1	2.2003E+02	7.4023E-06	1.4862E+07
K	0.0040640	0.0007239	0.5721	2808	117	2	6	1	2.1952E+02	7.5922E-06	1.4457E+07
K	0.0031877	0.0008509	0.5924	2808	117	2	6	1	1.6857E+02	6.2435E-06	1.3500E+07
K	0.0046736	0.0009144	0.5142	2808	117	2	6	1	4.0279E+02	1.0794E-05	1.8659E+07
K	0.0033909	0.0005715	0.5882	2808	117	2	6	1	1.8077E+02	5.0594E-06	1.7865E+07

K	0.0032893	0.0008890	0.6331	2808	117	2	6	1	2.3369E+02	6.7003E-06	1.7438E+07
K	0.0038354	0.0007239	0.4877	2808	117	2	30	2	2.3145E+02	7.0726E-06	1.6362E+07
K	0.0040259	0.0006985	0.4805	2808	117	2	30	2	2.4921E+02	7.2980E-06	1.7074E+07
K	0.0046482	0.0010033	0.4727	2808	117	2	30	2	3.4283E+02	1.1483E-05	1.4928E+07
K	0.0037338	0.0008509	0.5436	2808	117	2	30	2	2.6273E+02	7.7026E-06	1.7055E+07
K	0.0033338	0.0006858	0.4843	2808	117	2	30	2	2.1866E+02	5.7021E-06	1.9174E+07
K	0.0036703	0.0006731	0.5503	2808	117	2	30	2	1.2812E+02	6.3347E-06	1.0113E+07
K	0.0035814	0.0008001	0.4647	2808	117	2	30	2	2.7079E+02	6.9875E-06	1.9377E+07
K	0.0035052	0.0007874	0.3101	2808	117	2	30	2	2.7526E+02	6.7196E-06	2.0482E+07
K	0.0043942	0.0010922	0.3958	2808	117	2	78	3	3.4817E+02	1.1324E-05	1.5373E+07
K	0.0036576	0.0006731	0.4440	2808	117	2	78	3	1.9141E+02	6.3079E-06	1.5172E+07
K	0.0046228	0.0008890	0.4241	2808	117	2	78	3	4.3880E+02	1.0423E-05	2.1050E+07
K	0.0036830	0.0008001	0.4172	2808	117	2	78	3	2.5052E+02	7.2428E-06	1.7295E+07
K	0.0039878	0.0009017	0.2155	2808	117	2	78	3	3.4121E+02	8.7378E-06	1.9525E+07
K	0.0030988	0.0007874	0.3452	2808	117	2	78	3	1.9229E+02	5.7148E-06	1.6824E+07
K	0.0035306	0.0008128	0.3818	2808	117	2	78	3	1.6900E+02	6.9364E-06	1.2182E+07
K	0.0036068	0.0005969	0.3777	2808	117	2	78	3	1.9138E+02	5.6414E-06	1.6963E+07
K	0.0028956	0.0004572	0.1367	2808	117	2	150	4	9.0525E+01	6.5818E-06	6.8769E+06
K	0.0030861	0.0006350	0.1866	2808	117	2	150	4	1.1680E+02	7.4764E-06	7.8114E+06
K	0.0032893	0.0006350	0.1953	2808	117	2	150	4	1.5016E+02	8.4933E-06	8.8398E+06
K	0.0030480	0.0004191	0.1855	2808	117	2	150	4	1.2237E+02	7.2929E-06	8.3897E+06
K	0.0037795	0.0006350	0.2941	2808	117	2	150	4	2.4937E+02	1.1214E-05	1.1119E+07
K	0.0043307	0.0008890	0.1705	2808	117	2	150	4	3.1500E+02	1.4723E-05	1.0698E+07
K	0.0047625	0.0007493	0.2456	2808	117	2	150	4	3.0201E+02	1.7805E-05	8.4810E+06
K	0.0036195	0.0007620	0.3200	2808	117	2	150	4	3.3459E+02	1.0284E-05	1.6267E+07
K	0.0033020	0.0007874	0.1244	2808	117	2	246	5	1.5933E+02	6.2172E-06	1.2814E+07
K	0.0035560	0.0008890	0.1009	2808	117	2	246	5	1.5395E+02	7.4448E-06	1.0339E+07
K	0.0031623	0.0006096	0.1032	2808	117	2	246	5	1.2579E+02	4.8862E-06	1.2872E+07
K	0.0032766	0.0006350	0.1115	2808	117	2	246	5	1.2285E+02	5.2671E-06	1.1663E+07
K	0.0035560	0.0005842	0.1328	2808	117	2	246	5	2.2779E+02	5.4514E-06	2.0893E+07
K	0.0041656	0.0009017	0.1560	2808	117	2	246	5	3.9875E+02	9.2412E-06	2.1574E+07
K	0.0034290	0.0008128	0.1149	2808	117	2	246	5	3.4262E+02	6.6770E-06	2.5657E+07
K	0.0035560	0.0008128	0.1704	2808	117	2	246	5	2.1646E+02	7.0012E-06	1.5459E+07
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K	0.0031496	0.0007366	0.5473	3144	131	3	6	1	1.9632E+02	9.4808E-06	1.0354E+07
K	0.0038100	0.0007112	0.5447	3144	131	3	6	1	3.1446E+02	6.9201E-06	2.2721E+07
K	0.0036576	0.0008763	0.4721	3144	131	3	6	1	3.0949E+02	7.6530E-06	2.0220E+07
K	0.0038862	0.0008763	0.5399	3144	131	3	6	1	3.2402E+02	8.2820E-06	1.9562E+07
K	0.0038989	0.0007112	0.6234	3144	131	3	6	1	2.0814E+02	7.1187E-06	1.4619E+07
K	0.0037719	0.0007874	0.6490	3144	131	3	6	1	1.9893E+02	7.3790E-06	1.3480E+07
K	0.0031750	0.0006223	0.6803	3144	131	3	6	1	1.1175E+02	4.9880E-06	1.1202E+07
K	0.0033147	0.0007112	0.6145	3144	131	3	6	1	1.6274E+02	5.8141E-06	1.3996E+07
K	0.0047244	0.0007620	0.6878	3144	131	3	6	1	2.0954E+02	9.4808E-06	1.1051E+07
K	0.0035687	0.0006858	0.4327	3144	131	3	30	2	4.4165E+02	8.2005E-06	2.6929E+07
K	0.0027051	0.0006350	0.4681	3144	131	3	30	2	3.1627E+02	4.1595E-06	3.8018E+07
K	0.0045720	0.0006985	0.4378	3144	131	3	30	2	3.1321E+02	8.4957E-06	1.8433E+07
K	0.0038481	0.0009906	0.4074	3144	131	3	30	2	3.7331E+02	8.8882E-06	2.1000E+07
K	0.0035941	0.0006477	0.4528	3144	131	3	30	2	2.3150E+02	5.9923E-06	1.9316E+07
K	0.0041910	0.0008890	0.5139	3144	131	3	30	2	2.6586E+02	9.2174E-06	1.4421E+07
K	0.0039878	0.0009652	0.5347	3144	131	3	30	2	2.4955E+02	9.1607E-06	1.3621E+07
K	0.0034544	0.0007874	0.5333	3144	131	3	30	2	2.1487E+02	6.5940E-06	1.6293E+07
K	0.0040259	0.0008128	0.5444	3144	131	3	30	2	3.4898E+02	8.2005E-06	2.1278E+07
K	0.0037465	0.0007620	0.4779	3144	131	3	30	2	2.4056E+02	7.1410E-06	1.6844E+07
K	0.0029718	0.0005461	0.3902	3144	131	3	30	2	1.0202E+02	4.1595E-06	1.2263E+07
K	0.0030734	0.0006477	0.2732	3144	131	3	78	3	1.7144E+02	4.9333E-06	1.7376E+07

K	0.0036068	0.0006858	0.3728	3144	131	3	78	3	2.7399E+02	6.2901E-06	2.1780E+07
K	0.0032258	0.0008382	0.2929	3144	131	3	78	3	3.3868E+02	6.2840E-06	2.6948E+07
K	0.0034163	0.0007747	0.4381	3144	131	3	78	3	2.7340E+02	6.4259E-06	2.1274E+07
K	0.0030099	0.0006477	0.3163	3144	131	3	78	3	1.8386E+02	4.8042E-06	1.9135E+07
K	0.0035560	0.0007366	0.4766	3144	131	3	78	3	2.1568E+02	6.5211E-06	1.6537E+07
K	0.0035687	0.0006223	0.4278	3144	131	3	78	3	1.9959E+02	5.7573E-06	1.7334E+07
K	0.0034036	0.0006731	0.3119	3144	131	3	78	3	2.2672E+02	5.7710E-06	1.9643E+07
K	0.0037338	0.0007112	0.2205	3144	131	3	150	4	2.9866E+02	6.7500E-06	2.2123E+07
K	0.0037846	0.0009017	0.1510	3144	131	3	150	4	3.7099E+02	8.1625E-06	2.2725E+07
K	0.0036322	0.0005842	0.1550	3144	131	3	150	4	2.2886E+02	5.5912E-06	2.0466E+07
K	0.0041275	0.0009906	0.2511	3144	131	3	150	4	4.6769E+02	9.7573E-06	2.3966E+07
K	0.0020828	0.0003683	0.1328	3144	131	3	150	4	7.0117E+01	1.9828E-06	1.7682E+07
K	0.0030480	0.0004191	0.1021	3144	131	3	150	4	7.9120E+01	3.4596E-06	1.1435E+07
K	0.0025273	0.0004953	0.1167	3144	131	3	150	4	1.5375E+02	3.1603E-06	2.4326E+07
K	0.0024892	0.0003647	0.1034	3144	131	3	150	4	7.4160E+01	2.4331E-06	1.5240E+07
K	0.0044704	0.0005969	0.2457	3144	131	3	150	4	2.0131E+02	7.2600E-06	1.3864E+07
K	0.0034290	0.0005842	0.1830	3144	131	3	150	4	1.3634E+02	5.2185E-06	1.3063E+07
K	0.0040386	0.0010160	0.0976	3144	131	3	246	5	2.8867E+02	9.6428E-06	1.4968E+07
K	0.0043053	0.0009398	0.1401	3144	131	3	246	5	4.5488E+02	9.9315E-06	2.2901E+07
K	0.0039624	0.0008001	0.1245	3144	131	3	246	5	2.3830E+02	7.9447E-06	1.4998E+07
K	0.0050673	0.0010668	0.0870	3144	131	3	246	5	6.3413E+02	1.3401E-05	2.3660E+07
K	0.0024257	0.0004953	0.1185	3144	131	3	246	5	8.1264E+01	3.0022E-06	1.3534E+07
K	0.0043688	0.0009144	0.2130	3144	131	3	246	5	4.3075E+02	9.9183E-06	2.1715E+07
K	0.0038608	0.0009271	0.0833	3144	131	3	246	5	4.7616E+02	8.5403E-06	2.7877E+07
K	0.0048514	0.0006985	0.1674	3144	131	3	246	5	1.8046E+02	9.1085E-06	9.9061E+06
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K	0.0047498	0.0008636	0.5797	3816	159	5	6	1	3.4369E+02	1.0538E-05	1.6307E+07
K	0.0036322	0.0006985	0.6745	3816	159	5	6	1	1.5668E+02	6.4345E-06	1.2175E+07
K	0.0033909	0.0007239	0.5855	3816	159	5	6	1	1.6485E+02	6.0622E-06	1.3597E+07
K	0.0040132	0.0007112	0.6302	3816	159	5	6	1	2.1202E+02	7.3739E-06	1.4376E+07
K	0.0036322	0.0008636	0.6594	3816	159	5	6	1	2.7438E+02	7.5076E-06	1.8274E+07
K	0.0031115	0.0007620	0.6259	3816	159	5	6	1	1.6160E+02	5.6216E-06	1.4373E+07
K	0.0029464	0.0006858	0.6550	3816	159	5	6	1	1.5051E+02	4.8680E-06	1.5459E+07
K	0.0032004	0.0007620	0.6915	3816	159	5	6	1	1.6614E+02	5.8343E-06	1.4238E+07
K	0.0040132	0.0008636	0.6586	3816	159	5	6	1	2.7380E+02	8.5408E-06	1.6029E+07
K	0.0039878	0.0008001	0.6969	3816	159	5	6	1	2.4263E+02	8.0085E-06	1.5148E+07
K	0.0035687	0.0006096	0.6684	3816	159	5	6	1	1.9226E+02	5.6641E-06	1.6972E+07
K	0.0035306	0.0008255	0.6196	3816	159	5	6	1	2.2485E+02	7.0118E-06	1.6034E+07
K	0.0023876	0.0004953	0.4703	3816	159	5	30	2	7.6554E+01	2.9430E-06	1.3006E+07
K	0.0036957	0.0007112	0.4629	3816	159	5	30	2	2.8943E+02	6.6649E-06	2.1713E+07
K	0.0032385	0.0008636	0.3184	3816	159	5	30	2	2.8755E+02	6.4400E-06	2.2325E+07
K	0.0036449	0.0007493	0.4066	3816	159	5	30	2	3.5828E+02	6.8128E-06	2.6294E+07
K	0.0043688	0.0008001	0.4573	3816	159	5	30	2	3.5700E+02	8.9657E-06	1.9909E+07
K	0.0037084	0.0006985	0.6310	3816	159	5	30	2	1.5949E+02	6.6016E-06	1.2080E+07
K	0.0046482	0.0008509	0.5601	3816	159	5	30	2	3.5152E+02	1.0146E-05	1.7324E+07
K	0.0035179	0.0005969	0.5422	3816	159	5	30	2	1.8828E+02	5.4747E-06	1.7195E+07
K	0.0031877	0.0007747	0.4977	3816	159	5	30	2	2.2617E+02	5.8698E-06	1.9266E+07
K	0.0038227	0.0007366	0.5226	3816	159	5	30	2	2.9183E+02	7.1379E-06	2.0442E+07
K	0.0038481	0.0009144	0.2769	3816	159	5	78	3	4.2107E+02	8.4233E-06	2.4994E+07
K	0.0034798	0.0006985	0.3725	3816	159	5	78	3	2.0670E+02	6.1002E-06	1.6942E+07
K	0.0033782	0.0006096	0.3654	3816	159	5	78	3	1.3699E+02	5.2995E-06	1.2925E+07
K	0.0041402	0.0006223	0.4540	3816	159	5	78	3	2.3790E+02	6.8741E-06	1.7304E+07
K	0.0033909	0.0005969	0.2526	3816	159	5	78	3	1.5581E+02	5.2367E-06	1.4876E+07
K	0.0038608	0.0007239	0.2504	3816	159	5	78	3	2.7656E+02	7.1303E-06	1.9393E+07
K	0.0033274	0.0006858	0.3830	3816	159	5	78	3	1.4047E+02	5.6885E-06	1.2347E+07

K	0.0041275	0.0007620	0.3333	3816	159	5	78	3	2.3042E+02	8.0526E-06	1.4307E+07
K	0.0036068	0.0006350	0.2097	3816	159	5	78	3	2.0345E+02	5.9255E-06	1.7167E+07
K	0.0029972	0.0005969	0.2670	3816	159	5	78	3	1.4512E+02	4.4988E-06	1.6129E+07
K	0.0035687	0.0005334	0.7737	3816	159	5	78	3	1.6011E+02	5.0838E-06	1.5748E+07
K	0.0029845	0.0003683	0.2164	3816	159	5	78	3	9.3363E+01	3.0255E-06	1.5429E+07
K	0.0038227	0.0007239	0.2753	3816	159	5	150	4	2.1506E+02	7.0437E-06	1.5266E+07
K	0.0043434	0.0006604	0.2984	3816	159	5	150	4	2.9616E+02	7.6373E-06	1.9389E+07
K	0.0027940	0.0005080	0.2158	3816	159	5	150	4	1.0919E+02	3.6464E-06	1.4973E+07
K	0.0040005	0.0008128	0.2780	3816	159	5	150	4	2.1829E+02	8.1356E-06	1.3416E+07
K	0.0036576	0.0005461	0.2572	3816	159	5	150	4	1.6680E+02	5.3355E-06	1.5632E+07
K	0.0034798	0.0009779	0.2526	3816	159	5	150	4	3.1564E+02	7.6824E-06	2.0543E+07
K	0.0040132	0.0005842	0.2870	3816	159	5	150	4	1.9726E+02	6.2901E-06	1.5680E+07
K	0.0037338	0.0009550	0.2883	3816	159	5	150	4	3.7262E+02	8.3330E-06	2.2358E+07
K	0.0036576	0.0006731	0.2042	3816	159	5	150	4	2.9845E+02	6.3079E-06	2.3657E+07
K	0.0047117	0.0008001	0.2361	3816	159	5	150	4	2.9371E+02	9.8272E-06	1.4944E+07
K	0.0037211	0.0006731	0.1393	3816	159	5	150	4	2.5272E+02	6.4421E-06	1.9615E+07
K	0.0032893	0.0007747	0.2775	3816	159	5	150	4	3.2458E+02	6.1169E-06	2.6531E+07
K	0.0036957	0.0005334	0.2667	3816	159	5	178		1.2983E+02	5.2965E-06	1.2256E+07
K	0.0026797	0.0006477	0.1199	3816	159	5	178		1.5002E+02	4.1326E-06	1.8151E+07
K	0.0025654	0.0005588	0.1689	3816	159	5	178		1.3692E+02	3.5208E-06	1.9445E+07
K	0.0033274	0.0005207	0.1284	3816	159	5	178		1.2775E+02	4.5890E-06	1.3920E+07
K	0.0036068	0.0006096	0.1050	3816	159	5	178		2.2765E+02	5.7371E-06	1.9840E+07
K	0.0032258	0.0005715	0.2161	3816	159	5	178		1.4405E+02	4.7632E-06	1.5122E+07
K	0.0029210	0.0005461	0.1082	3816	159	5	178		7.6011E+01	4.0724E-06	9.3325E+06
K	0.0035306	0.0007620	0.2696	3816	159	5	178		2.4189E+02	6.6244E-06	1.8258E+07
K	0.0027051	0.0003683	0.1325	3816	159	5	178		7.1327E+01	2.7024E-06	1.3197E+07
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K	0.0027051	0.0004572	0.6065	3480	145	4	6	1	1.1685E+02	3.2271E-06	1.8105E+07
K	0.0028575	0.0006731	0.6378	3480	145	4	6	1	1.4784E+02	4.6168E-06	1.6012E+07
K	0.0038735	0.0007366	0.5041	3480	145	4	6	1	3.4752E+02	7.2554E-06	2.3949E+07
K	0.0036322	0.0007874	0.5854	3480	145	4	6	1	2.7737E+02	7.0336E-06	1.9718E+07
K	0.0040513	0.0009144	0.5161	3480	145	4	6	1	4.4452E+02	9.0067E-06	2.4677E+07
K	0.0035560	0.0007747	0.5460	3480	145	4	6	1	3.1637E+02	6.7657E-06	2.3381E+07
K	0.0032639	0.0007493	0.5894	3480	145	4	6	1	2.7150E+02	5.9164E-06	2.2945E+07
K	0.0038608	0.0006985	0.5911	3480	145	4	6	1	2.6185E+02	6.9358E-06	1.8877E+07
K	0.0039751	0.0008636	0.6519	3480	145	4	6	1	2.2172E+02	8.4375E-06	1.3139E+07
K	0.0036449	0.0007747	0.6117	3480	145	4	6	1	3.1901E+02	6.9819E-06	2.2846E+07
K	0.0037592	0.0008001	0.5918	3480	145	4	6	1	2.9498E+02	7.4342E-06	1.9839E+07
K	0.0033655	0.0006223	0.6141	3480	145	4	6	1	1.6522E+02	5.3603E-06	1.5411E+07
K	0.0040005	0.0006985	0.4525	3480	145	4	30	2	3.1157E+02	7.2422E-06	2.1511E+07
K	0.0032004	0.0006477	0.4587	3480	145	4	30	2	1.8000E+02	5.1916E-06	1.7335E+07
K	0.0031877	0.0005334	0.4585	3480	145	4	30	2	1.9667E+02	4.4456E-06	2.2119E+07
K	0.0044831	0.0006858	0.5329	3480	145	4	30	2	2.9190E+02	8.1772E-06	1.7848E+07
K	0.0033020	0.0006985	0.4371	3480	145	4	30	2	2.8463E+02	5.7102E-06	2.4923E+07
K	0.0036576	0.0007366	0.4390	3480	145	4	30	2	3.5301E+02	6.7561E-06	2.6125E+07
K	0.0037719	0.0006858	0.4849	3480	145	4	30	2	2.2479E+02	6.6456E-06	1.6913E+07
K	0.0035687	0.0006985	0.5103	3480	145	4	30	2	2.8569E+02	6.2952E-06	2.2692E+07
K	0.0029845	0.0006223	0.4203	3480	145	4	30	2	1.8455E+02	4.6158E-06	1.9991E+07
K	0.0034671	0.0008382	0.4844	3480	145	4	30	2	3.2862E+02	6.9191E-06	2.3747E+07
K	0.0038735	0.0007874	0.3560	3480	145	4	54	3	1.9688E+02	7.6302E-06	1.2902E+07
K	0.0026924	0.0006477	0.3333	3480	145	4	54	3	1.3003E+02	4.1585E-06	1.5635E+07
K	0.0036449	0.0008001	0.4342	3480	145	4	54	3	4.0801E+02	7.1470E-06	2.8544E+07
K	0.0032512	0.0006604	0.3327	3480	145	4	54	3	2.1567E+02	5.3724E-06	2.0072E+07
K	0.0033147	0.0007874	0.3878	3480	145	4	54	3	2.3548E+02	6.2486E-06	1.8843E+07
K	0.0035433	0.0007366	0.4899	3480	145	4	54	3	2.4334E+02	6.4917E-06	1.8743E+07

K	0.0040640	0.0007366	0.4563	3480	145	4	54	3	2.5385E+02	7.6960E-06	1.6492E+07
K	0.0047371	0.0006858	0.4629	3480	145	4	54	3	2.5306E+02	8.7241E-06	1.4503E+07
K	0.0035560	0.0007366	0.4681	3480	145	4	54	3	2.4661E+02	6.5211E-06	1.8909E+07
K	0.0037973	0.0007366	0.4953	3480	145	4	54	3	2.1865E+02	7.0792E-06	1.5443E+07
K	0.0036957	0.0006350	0.1037	3480	145	4	174	4	2.1289E+02	6.1027E-06	1.7442E+07
K	0.0035179	0.0007239	0.1028	3480	145	4	174	4	1.8394E+02	6.3509E-06	1.4482E+07
K	0.0037592	0.0007112	0.1345	3480	145	4	174	4	3.9348E+02	6.8067E-06	2.8904E+07
K	0.0038354	0.0007239	0.0963	3480	145	4	174	4	1.9958E+02	7.0726E-06	1.4109E+07
K	0.0027305	0.0005461	0.0997	3480	145	4	174	4	9.9996E+01	3.7457E-06	1.3348E+07
K	0.0040132	0.0007112	0.0813	3480	145	4	174	4	2.7372E+02	7.3739E-06	1.8560E+07
K	0.0032004	0.0007112	0.1337	3480	145	4	174	4	1.1406E+02	5.5588E-06	1.0259E+07
K	0.0028194	0.0006477	0.1003	3480	145	4	174	4	1.6739E+02	4.4168E-06	1.8949E+07

Vita

Manlu Yu was born in Shenyang, Liaoning, P. R. China in 1966. She received her Bachelor of Engineering degree in the Department of Mechanical Engineering at The Northeastern University, Shenyang, P. R. China in July 1988. She worked as a mechanical engineer in China after graduation. From 1997 to 2001, she studied and worked in France and Sweden in mechanical engineering field.

In August 2002, She entered the Graduate School of The University of Tennessee at Knoxville, U.S.A. in the Department of Biosystems Engineering and Environmental Science. There she majored in Biosystems Engineering with an emphasis in power and machinery and was awarded membership in Gamma Sigma Delta, honor society of agriculture. She was a member of the American Society of Agricultural Engineers. She was employed as a graduate research assistant in the two years study and awarded a Master of Science degree in Biosystems Engineering in August 2004.