INVESTIGATION OF A WATERMELON PULP FRUIT AND JUICE EXTRACTION DEVICE

By

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1997

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
In partial fulfillment of
The requirements for
The Degree of
MASTER OF SCIENCE
May, 2005

INVESTIGATION OF A WATERMELON PULP FRUIT AND

JUICE EXTRACTION DEVICE

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ACKNOWLEDGEMENTS

This research was supported by USDA Special Research Grant Number 2003-06134 & the Oklahoma Agricultural Experiment Station, Division of Agriculture & Natural Resources.

I would like to begin by thanking the members of my thesis committee for suggesting the research topic and guiding me through the entire study. Their expertise resulted in a fascinating quest for predictors.

My deep appreciation goes to Dr. N. O. Maness. His curiosity and enthusiasm helped me shape my research. I am thankful to him for providing me with steady supply of watermelons for my experiments.

I am highly thankful to Dr. T. J. Bowser who has provided me intellectual guidance and unlimited access to his lab so that I could conduct experiments.

Finally, it is to my major advisor, Dr. P. R. Weckler, that I owe an overwhelming debt of gratitude. Words are inadequate to express my thanks to him. I have yet to see the limits of his wisdom, patience, and selfless concern for his students. I thank him for providing the funding for my entire research. His critical reviews and suggestions were very helpful in the development of this research.

I am also thankful to Dr. M. Stone, Dr. J. Solie, H.O.D Dr. R. Elliot and staff members of BAE for their encouragement and support throughout the course of research. Sincere thanks are due to Mr. Wayne Kiner and the staff members of the BAE laboratory for timely fabrication of test bench.

I am thankful to fellow graduate students, Dr. Ruplal Choudhary, Mr. Ramesh Vishwanathan, Mr. Kean Liew and other friends who were helpful and supportive during my research.

Finally, I would like to thank my parents for their sacrifice and their encouragement without which I would not have been able to pursue my masters degree and achieve my goal.

Harish J. Bangera

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1 INTRODUCTION

1.1 SUMMARY

Lycopene is a red pigment and a powerful antioxidant that is found in plants. Antioxidants neutralize free radicals which may damage human tissues. The greatest sources of lycopene in fresh fruits and vegetables are watermelon, tomato, red grapefruit and guava.

Lycopene is part of a large group of plant compounds called carotenoids. Carotenoids are fat soluble and create yellow, orange or red colors in plants. Lycopene specifically is an open-chain unsaturated carotenoid that is responsible for the red color of watermelons, tomatoes, guavas, rosehips and pink grapefruits. The primary function of carotenoids in plants as necessary pigments is to neutralize compounds created during photosynthesis (NWPB, 2001). Of the carotenoids, lycopene is the most effective oxygen scavenger because it can neutralize several single oxygen atoms with a single lycopene molecule. Other antioxidants are Vitamin C (ascorbic acid) and Vitamin E (NWPB, 2001).

Lycopene received a significant amount of attention after a clinical study on human subjects found a strong negative correlation between lycopene in blood serum and the occurrence of prostrate cancer (Giovannucci et al., 1995). Lycopene may help prevent prostate cancer and some other forms of cancer, heart diseases, and other serious diseases (David, 2001).

Due to the increasing popularity of lycopene as a nutraceutical, scientists are interested in developing lycopene rich products and ingredients by extracting lycopene from watermelons and tomatoes. Because of the importance of lycopene as a phytonutrient, plant breeders are looking to develop new varieties of watermelons with high lycopene content. This research project was a part of a larger effort to extract lycopene from watermelons focusing on *in situ* juice extraction from watermelons.

Three methods have been reported for watermelon juice extraction and are listed below:

1. Manual removal of the red watermelon flesh, crushing this into juice and separating the water from the juice in a centrifuge (Gibson, 2000).
2. Boring a hole through the watermelon rind and squeezing the pulp out from the core (Beck, 1994).
3. Crushing the watermelon in a press and passing the pulp through a separator (Stella et al., 2003).

The limitations associated with these efforts were:

1. The equipment was not portable and could not be used in the field.
2. Waste (rind and seeds) disposal.
3. Extra work was required in separating the rind and the seeds from the juice.
4. The release of flavors and liquid components from the crushed rind into the pulp (methods 3 and 4)

1.2 OBJECTIVES

The main objective of this research was to make a portable device that would enable the extraction of juice from watermelons lying on the ground. The two specific objectives of the project were as follows:

1. To conduct laboratory tests aimed at finding the shear strength of watermelon flesh and rind.
2. To develop a device to extract the watermelon juice without crushing the rind.

1.3 CONCEPT

The basic concept for a watermelon juice extraction device was a handheld juicer that could be carried into the watermelon field. The mechanism would enter through the watermelon rind and mechanically shear the red watermelon flesh into juice. The juice formed inside the watermelon could then be transferred from the watermelon to a portable tank using a pump. The juice would then be available for further processing, that would allow for the extraction of lycopene.

1.4 SCOPE

1. Measure parameters that affect the rate of cutting watermelon flesh.
2. Design and fabricate a handheld watermelon juice extracting device.

2 REVIEW OF LITERATURE

2.1 SUMMARY

This chapter presents literature on watermelon juice and pulp extracting methods. Different watermelon cultivars, with respect to shape and size, are discussed in section 2.2. Since watermelon cultivars vary in shape and size, knowledge of this variation is important in designing shape and size of cutting mechanism. Review of equipment used for watermelon juice extraction and for fruits similar to watermelon is reported in section 2.3. Review of lycopene extraction from watermelon juice and the method associated with this research is briefly discussed in section 2.4.

2.2 FACTS ABOUT WATERMELON

Watermelon is a long-season crop that grows in a warm climate. Historically, total acreage for watermelon has been the second largest for a vegetable crop in Oklahoma (Roberts et al., 2003). Production is concentrated in the central and south-central areas of Oklahoma, but watermelon can be grown in most other areas of the state. A good watermelon yield under irrigation in Oklahoma is estimated to be eight tons per acre; however, the state average yield is about five tons per acre. Under ideal conditions over fifteen tons per acre have been achieved (Roberts et al., 2003).

Major types of watermelon produced in Oklahoma are Charleston Gray strains, Crimson Sweet, Jubilee, Allsweet, Royal Sweet, Sangria, triploid seedless, and Black

Diamond. Brief descriptions of several varieties grouped by rind color and fruit shape are listed in table 2.1 (Source: Roberts et al., 2003). The weights are average market sizes.

Table 2.1. Major watermelon varieties grown in Oklahoma

Group	Variety	Weight (kg)
Gray-green rind and round shape:	Mickylee	4.5
Gray-green rind and oblong shape:	Charleston Gray strains	11 - 16
Green-stripe rind and oblong shape:	Allsweet	11 - 16
	Jubilee	11 - 20
	Royal Jubilee	11 - 14
	Sangria	10 - 12
	StarBrite	10 - 13
	Tendergold (orange flesh)	10 - 13
Green-stripe rind and round oblong shape:	Crimson Sweet	9 - 14
	Royal Sweet	9 - 14
	Fiesta	10 - 12
	Madera	7 - 10
Green-stripe rind and round shape:	Petite Sweet	3 - 4.5
Green rind and round shape:	Black Diamond	14 - 22
	Texas Giant	14 - 22
	Florida Giant	14 - 22
	Desert King (yellow flesh)	9 - 5
Hybrid triploid (seedless)	Round, oval or oblong shape	5 - 9

Depending upon the variety and the season, watermelons reach harvest maturity in five to six weeks after pollination. An experienced farmer/cultivator could identify a ripe melon just by glancing at the glossy rind surface (Roberts et al., 2003). Other indications of ripeness include a change in the color of the ground spot from white to light yellow, change of the tendrils nearest the fruit from green to brown and thumping the fruit to see if a metallic sound is produced. A metallic ringing sound indicates immaturity and a more muffled, or dull sound indicates maturity or over maturity. Thumping is a reliable method that is used to detect over-maturity in round-shaped melons. The best method of determining ripeness is by cutting a few melons picked from various parts of the field.

In order to reduce chances of stem decay, melons are cut from the vine rather than pulled, twisted, or broken off. A long stem is left on the fruit. Melons are carefully handled, at all times, to avoid bruising. To avoid bruising and flesh separation from the rind, melons are never stood on end. They are never placed with the bottom side turned up as the ground spot is easily scalded by the sun. Melons are hauled from the field in straw or paper-padded containers to reduce bruising, punctures, and rind abrasion (Roberts et al., 2003).

After harvest, melons are directly loaded onto trucks for shipment to markets or to a central grading station for reloading and shipment. They are usually graded and sized during the loading operation. Traditionally, melons have been bulk hauled in trucks. The use of containers have recently gained popularity because they are more efficient during unloading, and injuries related to rough handling during loading and unloading are reduced (Roberts et al., 2003). Bulk bins made of corrugated fiberboard and holding around 1,000 pounds, as well as cartons holding three to five melons are used.

If necessary, watermelons can be kept for 2 to 3 weeks at a temperature of 52°F to 60°F. Relative humidity should range from 85% to 90%; higher humidity may promote stem-end rot. Watermelons do not adapt well to long term storage. They are subject to chilling injury and lose flavor and color below 50°F (Roberts et al., 2003). Decay, mainly black rot, can be expected from watermelons previously stored at 50°F or lower. At higher temperatures, watermelons are subject to decay. Preserving watermelons for up to a week at room temperature can improve their color. However, after several weeks at room temperature they have a very poor flavor and texture. Watermelons are sensitive to ethylene and should not be stored or shipped with products that emit ethylene, such as ripe cantaloupes, apples, pears, tomatoes, and bananas. The sugar content does not increase after harvest; however, watermelons may continue to develop their red color after a slightly immature melon is picked (Roberts et al., 2003). Storing for longer a period of time can over ripen the watermelon and decrease the lycopene content (Maness, 2004).

An important consideration in successful marketing is to have adequate facility to transport the watermelons to market outlets. Quality and maturity are of prime importance in marketing watermelons (Roberts et al., 2003). The percentage of water in watermelon fruit is very high; watermelon is 92 percent water by weight, the highest percentage that is found in any fruit.

It was noted that activities like harvesting, transporting and storing watermelons need considerable attention, time, manpower and money. These activities seemed superfluous if the sole purpose was to extract lycopene. These activities can be bypassed if equipment for extracting watermelon juice in the field is made available.

2.3 CURRENT METHODS IN WATERMELON JUICE EXTRACTION

Few methods have been developed for extracting juice from watermelons and similar fruits. These equipments were heavy and not portable.

Beck (1994) developed an apparatus as shown in figure 2.1 for extracting the juice from a whole fruit. It had a piston and a pressing head arrangement that moved reciprocally towards and away from each other. Watermelons were squeezed between the piston and pressing head and the juice was collected in a reservoir. Although the method was fast, it required the added process of separating seeds and rind from the juice. Moreover, the disposal of the waste produced required additional time and money. This method did not eliminate the handling and transportation cost of moving watermelons from the field to the factory.

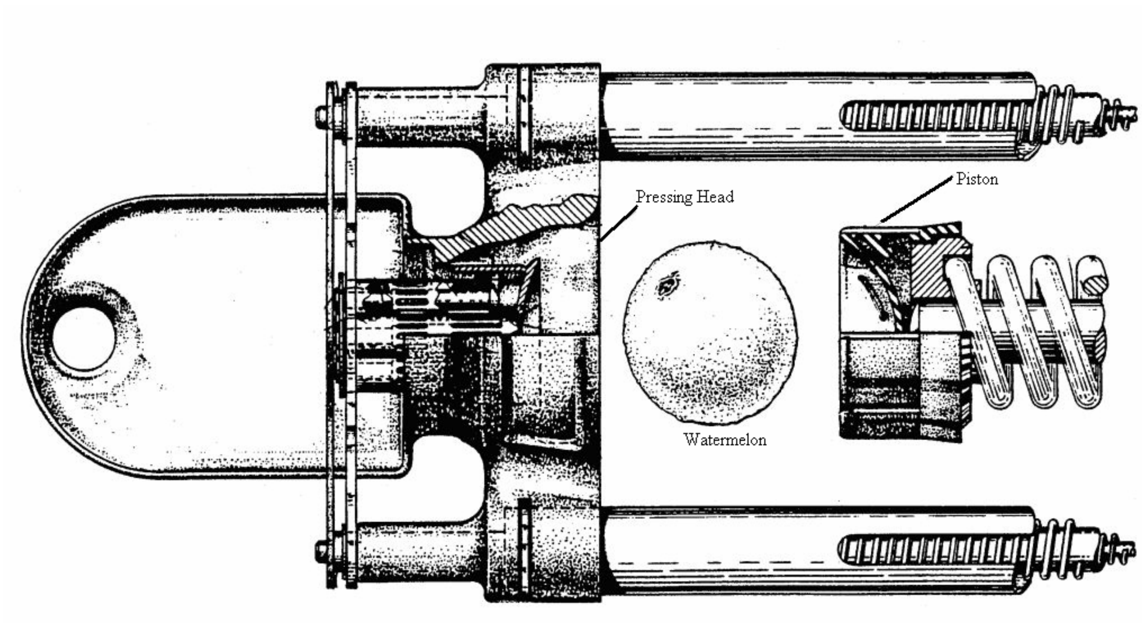


Figure 2.1: Drawing of machine used for extracting fruit juice (Source: Beck, 1994)

There is disclosed patent on a device in Hoffseth (1997) for removal of rind from melons. This method requires pre cut watermelon sections, and peeling the rind from each section of watermelon consumes considerable time. This process would be more suitable for fruits with a soft rind. Figure 2.2 shows the machine used by Hoffseth (1997) for peeling rind from pre cut melons.

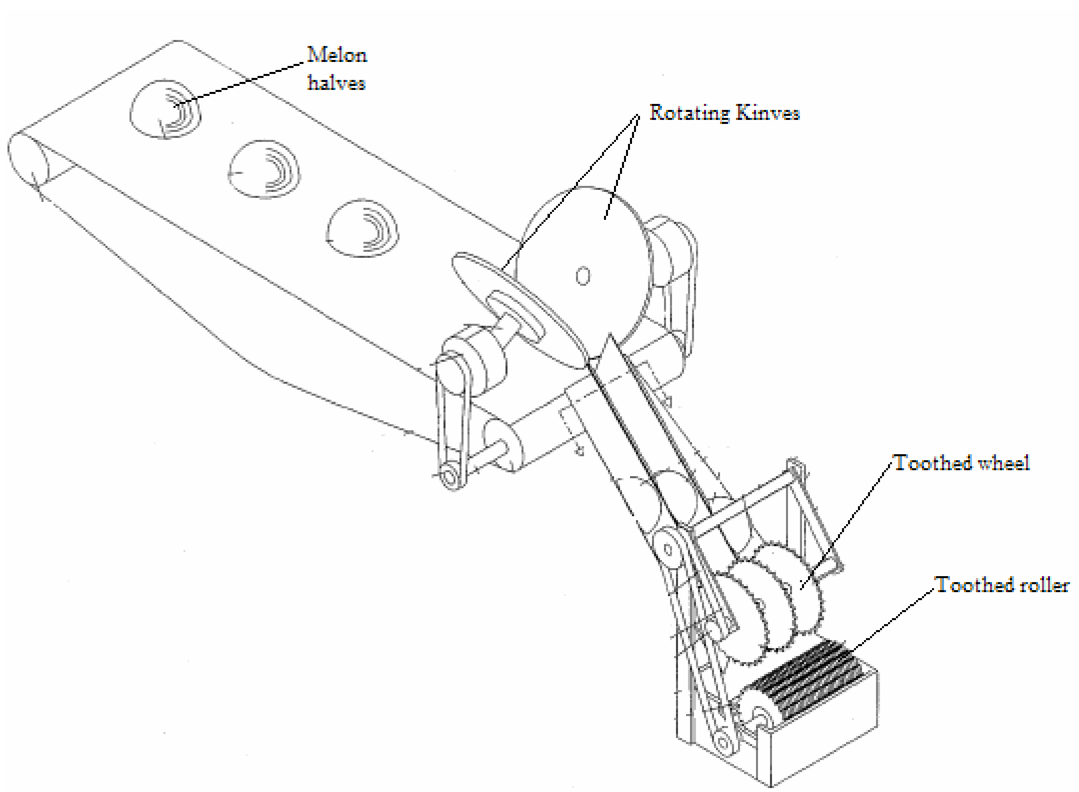


Figure 2.2: Drawing of melon rind trimming device (Source: Hoffseth, 1997)

Martin (2000) discusses a peeling machine for peeling vegetables and fruits. The peeling machine had a stationary lower holding assembly and a rotating upper holding assembly as shown in figure 2.3. An air cylinder pushed the lower assembly towards the upper holding assembly and held the fruit or vegetable between the two holding assemblies. A carriage containing a cutting device moved vertically up and down. This carriage assembly was connected to the end of a second air cylinder. The second air cylinder pushed the cutting device towards and away from the fruit as the vertical carriage assembly moved upward or downwards, peeling the rind from the fruit or vegetable. The drawback of this process is that it can be time consuming because watermelon rind is much harder and thicker than other fruits. Thus removing the entire rind with this method may consume a significant amount of time.

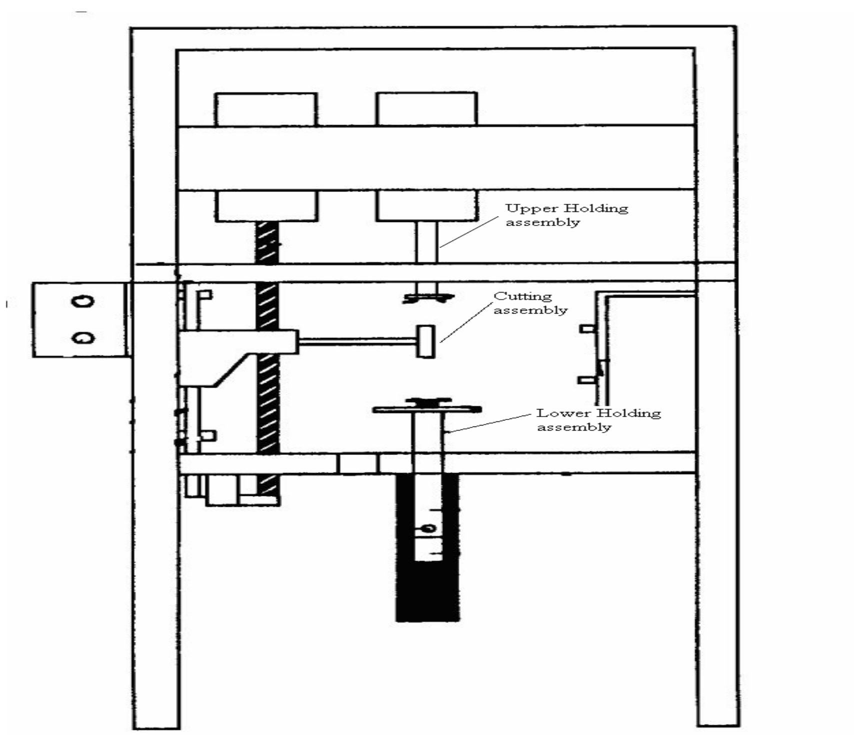


Figure 2.3: vegetable/fruit peeler (Source: Martin, 2000)

Stella et al., (2003) discuss a process for making a commercially packaged watermelon fruit juice drink. According to this process, juice was extracted from the whole watermelon, except the seeds. The process used a press to extract the juice. The press could be adjusted to vary the amount of pressure that was applied to the fruit. Pressure was adjusted so that the seeds were not crushed or broken. This method crushed the entire fruit which resulted in mixing the seeds and the rind with the watermelon juice. An additional separator was required to remove the rind and seeds.

2.4 CURRENT METHODS OF LYCOPENE EXTRACTION

Ausich, et al., (1999) discuss a process for isolating and purifying lycopene crystals from a biological lycopene source. A lycopene-containing oleoresin was saponified in a composition of propylene glycol and aqueous alkali to form lycopene crystals. Crystallization was achieved without the use of added organic solvents. The crystals were isolated and purified. The substantially pure lycopene crystals obtained were suitable for human consumption and could be used as a nutritional supplement and as an additive in food.

Vaughn et al., (2003) used supercritical fluid extraction (SFE) of refrigerator dried watermelon tissue with CO_2 to extract lycopene. Preliminary studies have shown an ethanol modifier to be more effective in extracting lycopene.

A unique procedure to extract lycopene from watermelons related to this research is described in Maness et al. (2002). Red watermelon flesh is ground and homogenized using a homogenizer. The ground flesh is then filtered through mira cloth under vacuum. Filtrates from the filtration were subsequently passed through a centrifuge to precipitate lycopene. Samples for lycopene and sugar analysis were taken at appropriate steps during the process and then analyzed using a spectrophotometer and high performance liquid chromatography (HPLC) respectively. The combined filtration processing and filtrate precipitation steps represent a means of concentrated watermelon lycopene into two fractions: a filter cake and filtrate pellet with a combined mass of less than 10% of the original melon weight. Lycopene recovery varied from 35-55% depending on maturity. This method of lycopene extraction was used on watermelon juice extracted from the equipment covered in this thesis.

The number of reference articles discussing lycopene extraction methods indicates the vast potential of lycopene as a nutritional supplement. Watermelon juice could be an easy source for lycopene extraction if a portable device for watermelon juice extraction from a watermelon in the field is available. A portable device would eliminate cost of harvesting, handling and transporting watermelon from field to processing unit. Past development of watermelon juice extraction equipment has not resulted in a portable machine.

3 MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter has three main parts; section 3.2 describes the method and equipment used for shear strength measurement of red watermelon flesh and rind. Section 3.3 describes experiments conducted with a prototype “3-blade assembly”. Section 3.4 describes the cutting sequence of the blades inside the watermelon. Before designing 3-blade assembly some preliminary test were conducted with plastic string as cutting blade. The test and observation of the test conducted with plastic string is described in Appendix H. The test with plastic string as cutting blade was the basis of designing 3-blade assembly.

3.2 SHEAR FORCE LAB TEST

3.2.1 SAMPLES

Watermelons used for this study were grown at the Oklahoma Vegetable Research Station, Bixby, Oklahoma in 2004. Watermelons grown at the research station at Bixby were the seedless cultivar ‘Sugar Shack’ and were either mature or under-mature when harvested.

Watermelon shear strength was determined from cubes of watermelon, which were cut by hand. Samples were cut from the red watermelon flesh and rind. Sample cubes measuring 30x30x30 mm were cut from two sections of the watermelon fruit; both regions are shown in figure 3.1. Region I was the rind (approximately 10 to 15 mm thick) and region II was the red watermelon flesh adjacent to the rind (approximately 10 to 20 mm thick). The samples cut from region I includes some red portion near the rind making total thickness of sample 30 mm although the thickness of rind was 10-15 mm. If the samples were cut at the boundary between region I and region II then there was a chance of damaging the rind surface since all samples were cut by hand. The rind surface would become softer and the shear force measured would not be correct. Therefore the samples include some red portion near the rind. Similarly samples from region II include some red flesh adjacent to it making the sample thickness as 30 mm even though the actual size of region II was 10-20 mm. The main aim of this shear test was to measure the maximum shear strength of watermelon in region I and II and not to measure shear strength at every individual point in the region I and II. A total of six watermelons were used. A sample from region I and one from region II were taken from each watermelon. Thus, six samples of red watermelon flesh and six samples of rind were tested to measure their shear strength. Whole watermelons were used to test the prototype, 3-blade assembly.

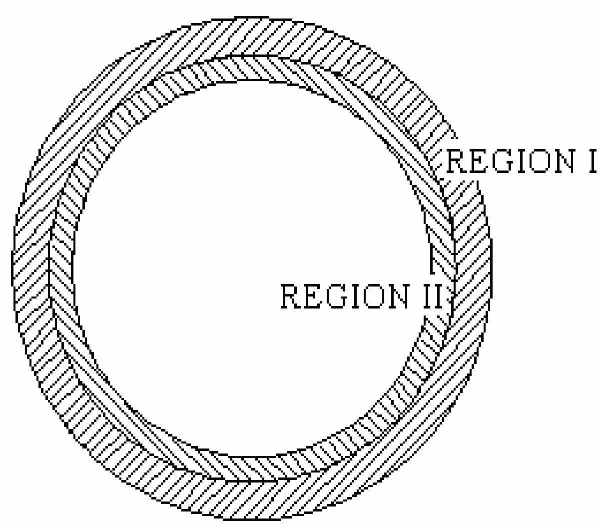


Figure 3.1: Schematic figure of a cross-section of a watermelon showing regions of sample taken for shear test.

3.2.2 SHEAR TEST INSTRUMENTATION

Shear strengths of the red watermelon flesh and rind were measured using an MTS® Sinetech™ machine (Renew 1122ADC, MTS Sintech, Eden Prairie, MN). This machine is also commonly known as an Instron testing machine. Figure 3.2 shows a schematic figure of the Instron machine with the shear blade attached to its crosshead. Two kinds of blades were made to cut the watermelon samples. These blades were attached separately to the Instron machine crosshead and shear force reading was measured with each blade. The crosshead moved vertically. The first blade had a cutting edge thickness measuring 2 mm, while the second blade had a cutting edge thickness of 19 mm. Figures 3.3 and 3.4 shows 2 mm and 19 mm thickness blade respectively attached to the Instron machine crosshead. The Instron machine records the force required to shear with respect to the penetration of the blade into the sample. The data was measured and stored using TestPad® software (Version 1.02, Instron, Canton, MA) and was analyzed using Microsoft Excel™ software (Version 95, Microsoft Corporation, Redmond, WA). The maximum crosshead speed of this Instron machine was 1270 mm/min and the minimum speed was 0.001 mm/min.

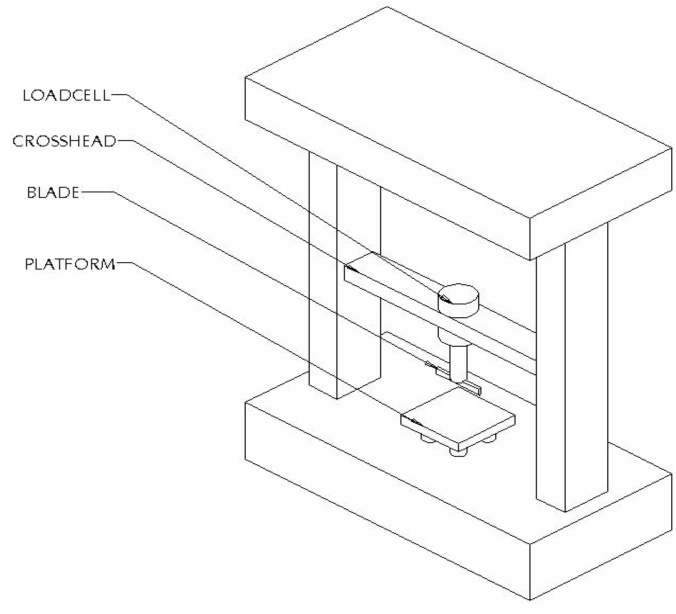


Figure 3.2: Schematic figure of MTS® Sinetech machine.

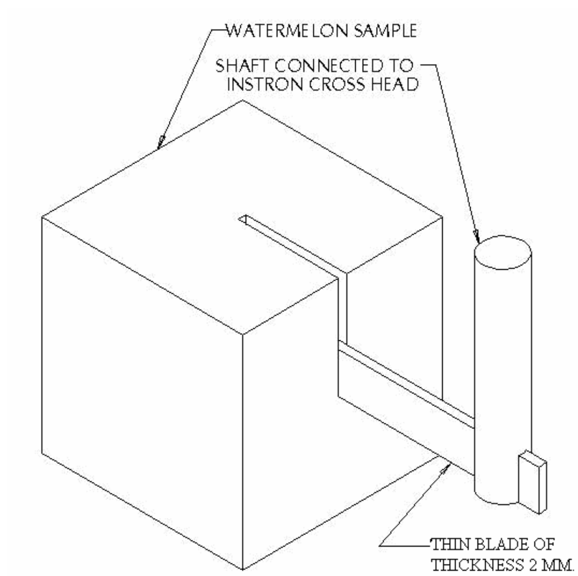


Figure 3.3: Schematic diagram of thin blade used in shear strength measurement.

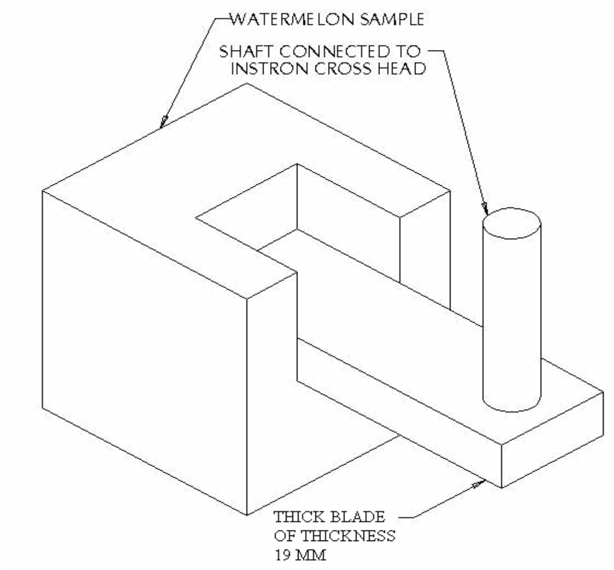


Figure 3.4: Schematic diagram of thick blade used in shear strength measurement.

3.2.3 MEASURING SHEAR STRENGTH OF WATERMELON SAMPLES

Cubes of red watermelon flesh and rind were placed separately on the Instron machine platform. Both blades (thin edge and thick edge) were used separately to cut the samples of red watermelon flesh and rind at three different cutting speeds. Cutting speed was the speed at which the crosshead of the Instron machine moved the blade vertically downward. A 500 kg load cell was used to measure the shear strength. The load cell was calibrated using standard weights supplied by the Instron machine manufacturer**.** Shear tests were conducted at three different crosshead speeds for each type of blade (1270, 635, and 0.001 mm/min). Values of force and penetration were plotted using Microsoft® Excel™ to determine the maximum shear stress required to cut red watermelon flesh and rind cubes. Spatial distribution of shear strength inside watermelon was measured by the Instron machine.

3.3 CUTTING BLADE DEVELOPMENT AND TESTING

3.3.1 SIMPLE 3-BLADE CUTTER

A simple, 3-blade cutter was made of aluminum as shown in figure 3.5. It had three blades placed 120 degrees apart from each other on a circular flat plate. The number of blades could vary depending on the user. The choice of three blades was coincidental and not due to any experimental result. A 12.5 mm diameter shaft, 533 mm in length was fixed to the circular plate. When the shaft was at rest, the position of the three blades was manually maintained as is shown in figure 3.6.b. If the shaft was rotated at high speed, the three blades opened and aligned themselves radially as shown in figure 3.6.a. In a rotating motion the blades opened up because of an outward centrifugal force. The power source used to rotate this device was a Dewalt (DW 928K-2, Dewalt Industrial Tool Co., Baltimore, MD) cordless drill machine. The battery of the cordless drill machine was modified to connect to an ammeter which could read the current drawn by the drill motor while cutting the watermelon flesh. A dial tachometer (Biddle indicator, James G. Biddle Co., Plymouth Township, PA) was used to measure the rotational speed of the shaft. After an analysis of the watermelon shear strength data and preliminary test with the 3-blade cutter (shown in figure 3.5), a prototype working model (see figure 3.7) was fabricated and tested.

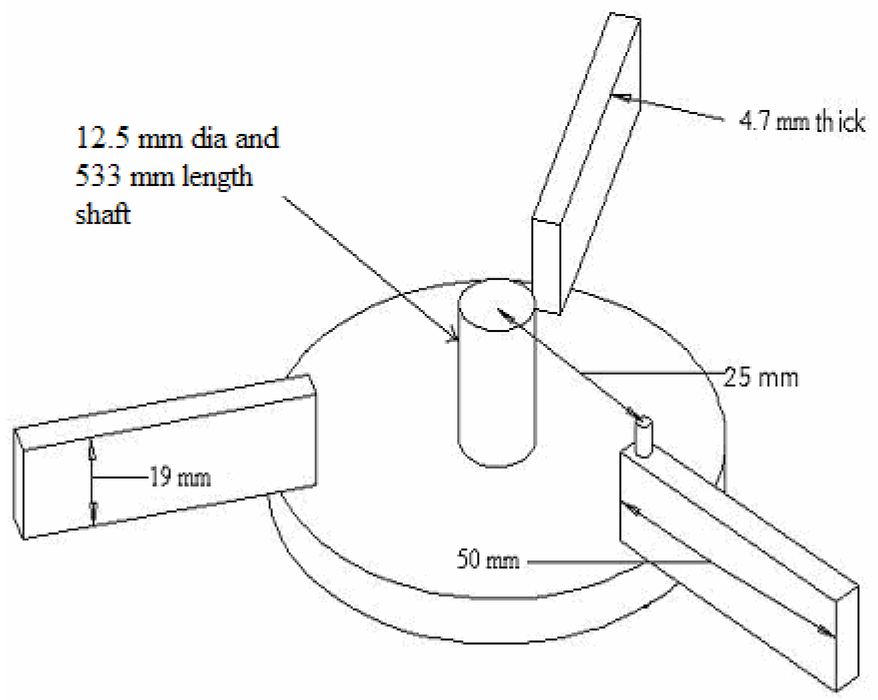
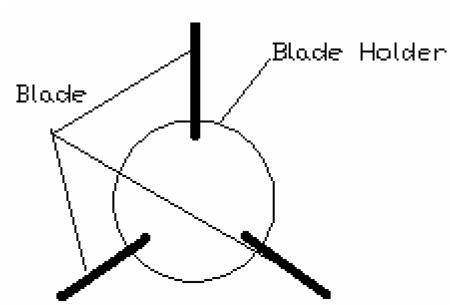


Figure 3.5: Schematic figure of the simple, 3-blade test cutter used for experiments.



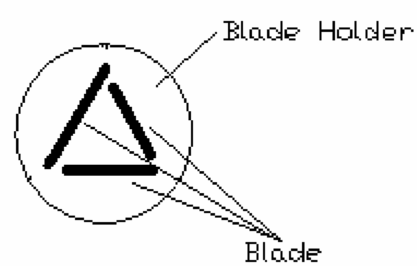


Figure 3.6.a **Figure 3.6.b**

Figure 3.6: Schematic figure of simple, 3-blade test cutter in open and closed position.

3.3.2 PARTS AND OPERATION OF PROTOTYPE 3-BLADE ASSEMBLY

The prototype, 3-blade assembly had a total of five important parts (see figure 3.7). Appendix A gives an assembly drawing, exploded view of the assembly, bill of material and dimensioned part drawing for the prototype, 3-blade assembly. The description of each part is as follows,

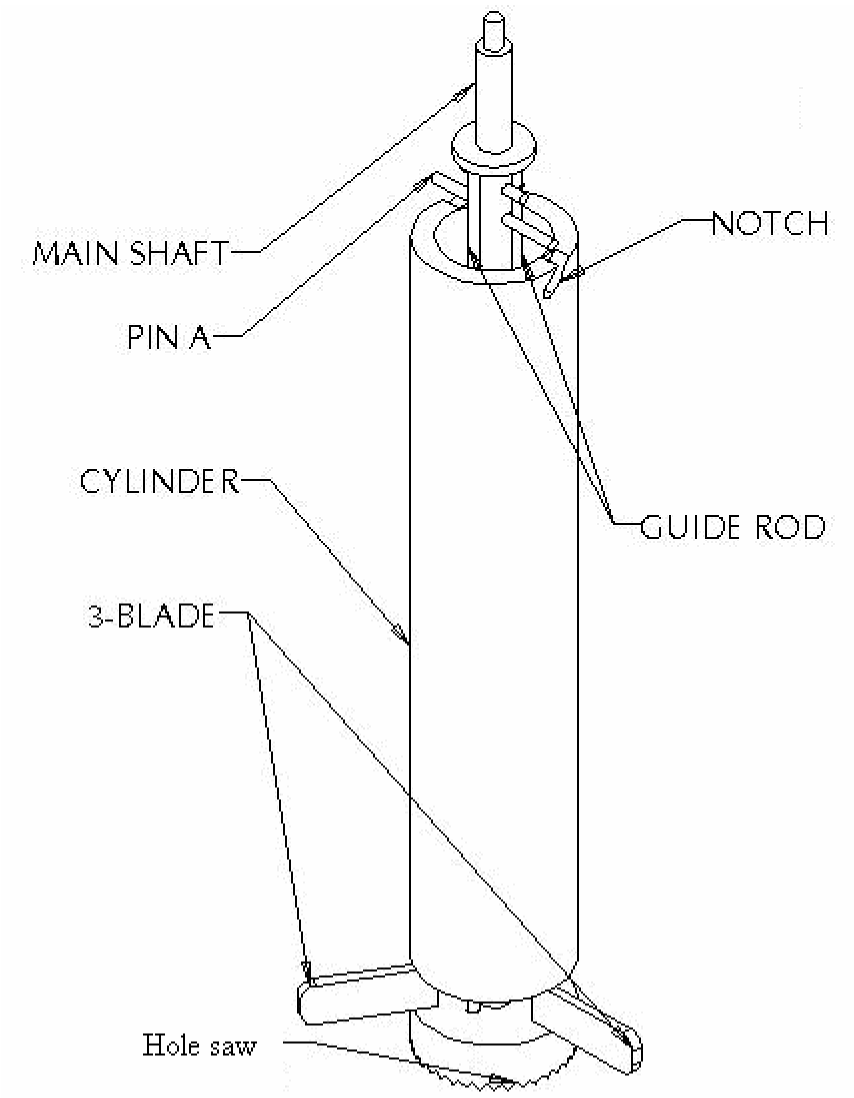


Figure 3.7: Schematic diagram of a prototype, 3-blade assembly

1. <u>Main shaft:</u> Supports all the parts. The top end of the shaft was connected to the drill chuck.
2. <u>Hole saw:</u> This was an industrial hole saw of diameter 68.58 mm and 25.4 mm cut depth (Product reference number 4066A45, McMaster-Carr, Atlanta, GA). The

original hole saw had 38.1 mm cut depth this was machined and reduced to 25.4 mm. The choice of 25.4 mm cut depth was coincidental. It was fixed to the bottom end of the main shaft. Its purpose was to bore a hole in the rind of the watermelon so that the interior could be accessed. Through this hole the blades of the 3-blade assembly entered the watermelon.

3. Guide rod: The guide rod was composed of a set of two rods. It could be pushed or pulled along the axis of the shaft to remove the portion of the rind cut by the hole saw after a hole that allowed access was cut.

4. Cylinder: The cylinder had a notch at its top end. The cylinder could be pulled up and connected with the main shaft using PIN A. Once the cylinder was connected with the pin A, it rotated the blades.

5. 3-Blade assembly: The three blades were supported by the cylinder. They were equally spaced 120 degrees apart from each other.

Operating sequence:

First an access hole was cut in the rind by the hole saw. While cutting the access hole the drill motor rotated only the hole saw; the 3-blade assembly did not rotate (as shown in figure 3.8.a) for safety reasons since the individual blades would have moved outward (shown in figure 3.8.b) creating a safety hazard. When the hole saw bored an access hole through the rind, the 3-blade assembly was outside of the watermelon (see figure 3.8.a). The Pin A and the notch on the cylinder ensured that the 3-blade assembly rotated only after entering the watermelon.

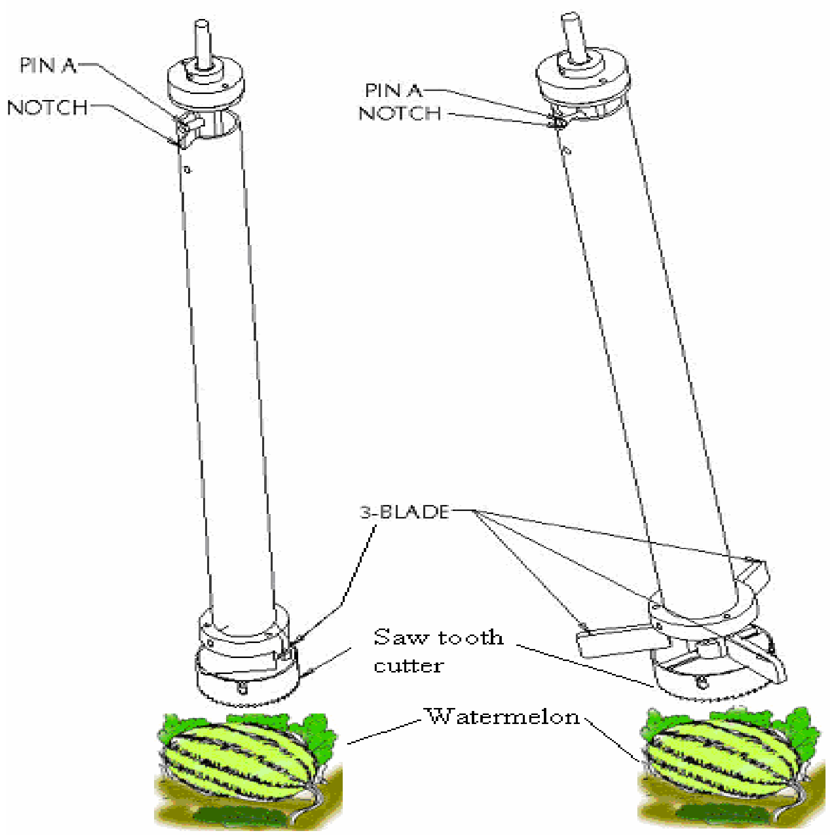


Figure 3.8.a **Figure 3.8.b**

Figure 3.8: Schematic diagram of prototype 3-blade assembly outside watermelon

The hole saw bored a cylindrical hole in the rind, but the bottom of the round-cut rind portion was still attached to the red flesh inside the watermelon (see figure 3.9).

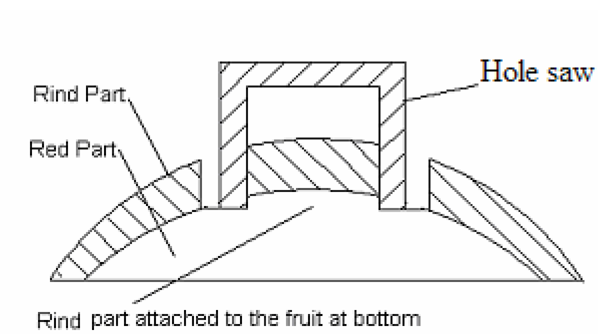


Figure 3.9: Cross-section of watermelon showing hole saw and piece of rind cut by it attached to rest of the fruit at bottom

Therefore, once the hole saw finished cutting the circular hole through the rind, the motor was stopped and the guide rod was pushed into the rind. With the hole saw and guide rod in the watermelon rind, the motor was switched ON. This sheared the round cut rind from the red watermelon flesh holding it from beneath. The motor was turned OFF and the 3-blade assembly was taken out of the melon. The guide rod was again pushed out to remove the rind piece stuck inside the hole saw. The hole saw and the 3-blade were pushed into the watermelon through the access hole and the motor was switched ON. The cylinder was pulled up and its notch was engaged with pin A. This transmitted enough motor power to the cylinder to be able to rotate. The three individual blades moved outward inside the watermelon and mechanically sheared the red watermelon flesh.

3.3.3 CRITERIA TO DETERMINE SATISFACTORY CUTTING SPEED

The criteria to determine a satisfactory cutting speed was the speed at which entire red watermelon flesh of a 200 mm diameter watermelon (spherical shape) was cut in two minutes using the 3-blade assembly. Rotational speed at which the 3-blade assembly could cut through a 20 mm thick rind in 15 seconds was considered to be satisfactory cutting speed. Thus, all the satisfactory rotational cutting speeds listed in any of the following sections were measured with respect to this criterion.

3.3.4 MEASURING CURRENT DRAWN BY MOTOR

An ammeter was used to measure the current drawn by the drill motor. The current was measured under two different conditions. The conditions tested were:

1. Current drawn with the 3-blade assembly fixed to the motor and no other load,
2. Current drawn while cutting red watermelon flesh using the 3-blade assembly.

Condition 1 gave the current drawn by the motor to overcome its internal resistance plus the current drawn to rotate the 3-blade assembly in air. The current measured in condition 2 was the sum of the current required to overcome the motor's internal resistance, current required to rotate the 3-blade assembly, and current required to cut the red watermelon flesh. The current required to cut only red watermelon flesh was calculated by subtracting the current measured in condition 1 from the current measured in condition 2. The voltage across the battery terminals was measured before and after the red watermelon flesh inside a watermelon was sheared completely. The battery was charged fully to it's capacity before every trail.

3.3.5 MEASURING MOTOR SPEED

A contact-type dial tachometer (Biddle indicator, James G. Biddle Co., Plymouth Township, PA) was used to measure the motor speed. The dial tachometer could not be directly attached to the motor to measure the speed while the 3-blade assembly cut the red watermelon flesh. Instead an indirect approach was used to measure the speed. Since the current drawn by a motor is directly proportional to its speed, current was measured while the 3-blade assembly cut the red watermelon flesh.

The process of measuring motor speed had following steps:

1. Current drawn by the motor while cutting red watermelon flesh was measured.
2. The 3-blade assembly was removed from the watermelon.
3. The 3-blade assembly was removed from the motor chuck.
4. The dial tachometer was fixed to the motor chuck (see figure 3.10).

5. The motor with the dial tachometer attached was run with no extra load on the motor.

6. A resistance to the motor rotation was gradually applied by holding the drill chuck manually, using a handkerchief for protection, until the current drawn by the motor increased and became equal to the current drawn in step 1.

7. The speed corresponding to the current in step 6 was measured using the dial tachometer. This speed was accepted as the satisfactory rotational speed that could be used to cut red watermelon flesh.

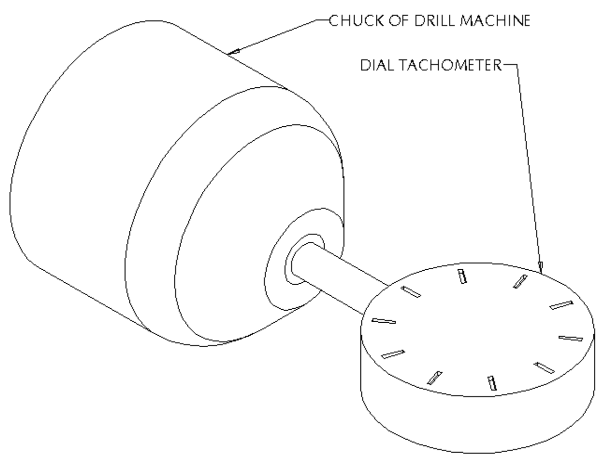


Figure 3.10: Schematic diagram showing dial tachometer held in drill machine chuck

3.3.6 REGULATING CUTTING SPEED

A modification was made to the electrical circuit of the drill machine to incorporate a rheostat. Refer to figure 3.11 for a circuit diagram showing the rheostat connected to the drill machine. Figure 3.12 shows the battery of the drill machine and the arrangement for ammeter and rheostat leads. The rheostat changed the resistance across the motor and the current drawn by the motor. The rheostat also changed the current and motor speed gradually. The motor speed was gradually increased using the rheostat, until a satisfactory rate of cutting (as per the criteria set in 3.3.3) was observed.

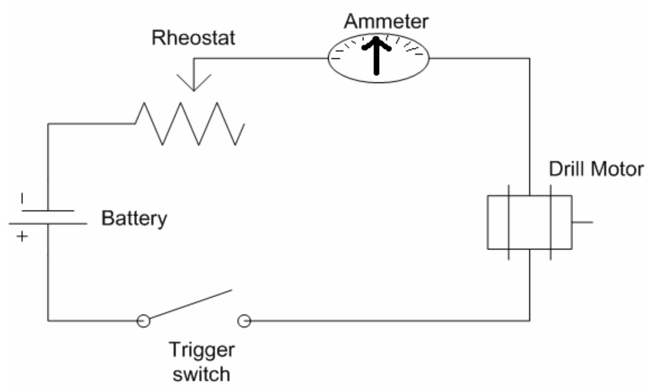


Figure 3.11: Circuit diagram for battery modification.

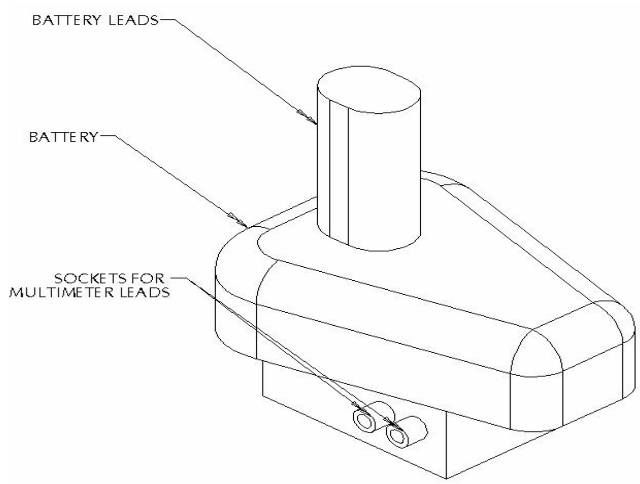


Figure 3.12: Schematic figure of battery modification

3.3.7 MEASURING IMPACT FORCE OF 3-BLADE ASSEMBLY (EXPERIMENTAL)

The Instron machine was used to measure the impact force exerted by each blade on the watermelon flesh. A flat plate was fixed to the Instron machine crosshead as shown in figure 3.13.

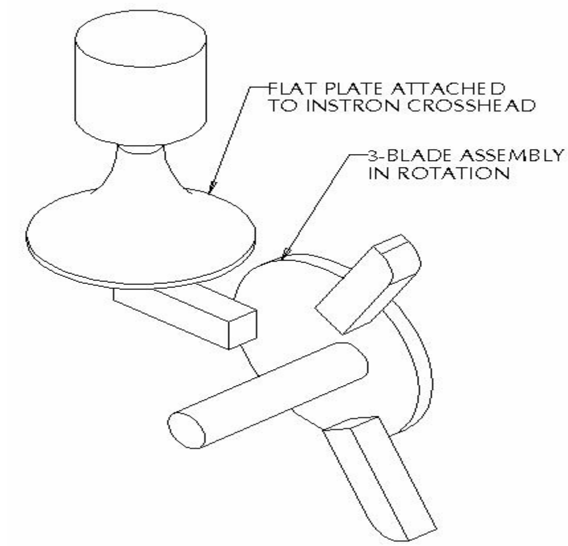


Figure 3.13: Schematic diagram showing method used to measure the impact force of 3-blade using an Instron

The 3-blade assembly was fixed to the drill motor and rotated at the satisfactory cutting speed. The tip of the blade was brought close to the flat plate so that the two came into contact. The impact force of the blade on the plate was measured by using the Instron machine software.

3.3.8 MEASURING NUMBER OF IMPACTS PER REVOLUTION

The total number of impacts of each blade inside the watermelon in one shaft revolution was calculated using two different approaches. This parameter is proportional to the rate of juice formation from solid red watermelon flesh. Higher the number of impacts per revolution higher would be the rate of juice formed. The formulae used in both methods shows the parameters which affect the number of impacts per revolution. The first method used was the approach described by McCutchen (2000) to calculate the impact force between a racquet and ball in tennis, and the second method used Newton's second law of motion. Figure 3.14 shows schematic diagram of tangential force acting on the fully opened blade. The resultant tangential force was assumed to act at the center of mass of the blade. The center of mass of the blade was assumed to be, at the midpoint of the length of the blade. For both methods the value of the impact force required for calculation was taken from section 3.3.7.

3.3.8.1 Method 1:

This method had been used to calculate the impact force of a racquet on a ball by a tennis player as shown by McCutchen (2000).

Impact Force = Impact Impulse/dwell time
Impact Impulse = Change in blade momentum
Dwell time = Time taken by blade to diminish from initial speed to zero speed

$$Impact\ force = (M/t)\left\{(1+c)\times\left[(\frac{2}{M})\times(W)\right]^{1/2} - (\frac{r}{d})\times(cS_1 + S_2)\right\} \qquad (3.1)$$

where,
Impact force is measured in Newton
M = *Mass of each blade (kg)*
t = *Dwell time i.e. time requried to reduce from initial velocity to zero velocity (sec)*
c = *Coefficient of restitution*
W = *Work done in imapct (N - m)*
r = *Distance between center of mass and axis of rotation (m)*
d = *Distance between impact point and axis of rotation (m)*
S_1 = *Linear velocity of blade before impact (m/s)*
S_2 = *Linear velocity of blade after impact (m/s)*

Before impact, the blades rotated at a particular initial rotational velocity. During impact, the initial rotational velocity decreased and diminished to zero. The time taken to diminish from the initial velocity to zero was called dwell time. Below is the procedure for calculating dwell time.

$$\begin{aligned}
&\textit{Let rotational speed} = X \textit{ rpm}\\
&\textit{Then time taken to complete one revolution} = 60/X \textit{ seconds}\\
&\textit{Let number of impacts per revolution} = Y\\
&\textit{Assume all Y impacts take same time to reach zero rpm from X rpm}\\
\\
&\textit{Then time taken by each impact} = 60/X \times Y \textit{ seconds}
\end{aligned}$$

Refer appendix G for calculating number of impacts per revolution.

3.3.8.2 Method 2:

According to Newton's second law of motion for linear translation,

$$Force = Mass \times Linear\ acceleration \qquad (3.2)$$

For a rotating body, the force is replaced by torque, mass by moment of inertia and linear acceleration by angular acceleration. Thus:

$$\begin{aligned}
&Torque = Moment\ of\ Inertia \times Angular\ acceleration\\
&Moment\ of\ Inertia = Mass \times (Distance\ between\ force\ and\ axis\ of\ rotation)^2\\
&Angular\ acceleration = change\ in\ angular\ speed/time
\end{aligned}$$

Time of the angular acceleration was the time required for the speed to diminish from the initial rotational value to zero during one impact. The dwell time was calculated by the method used in section 3.3.8.1. Also,

$$Torque = Force \times distance\ between\ force\ and\ axis\ of\ rotation \qquad (3.3)$$

Thus, knowing force and distance, the torque could be calculated. From the calculated torque, having knowledge of force and distance for the calculation of the torque, the angular acceleration could be calculated, and from this angular acceleration the number of impacts per revolution was ascertained. Refer to appendix G for an example calculation of the number of impacts in one revolution.

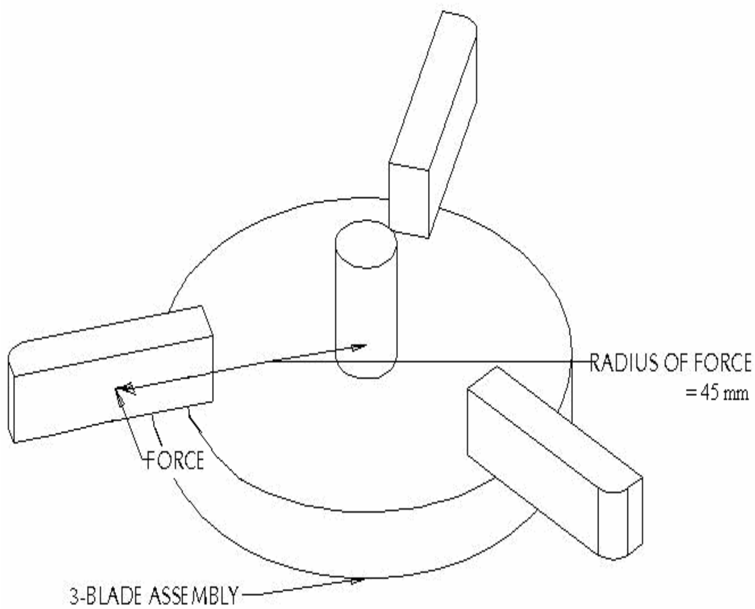


Figure 3.14: Schematic diagram showing point of application of impact force

3.4 CUTTING SEQUENCE

3.4.1 CUTTING SEQUENCE FOR 3- BLADE ASSEMBLY

In this research, a simulation was conducted using a half-cut watermelon (cut along the longitudinal axis) to study the cutting sequence of 3-blade assembly inside the watermelon. A half cut watermelon was used so that the movement of the blades could be visually observed. The 3-blade assembly was fixed to the drill motor. It was observed that when the motor was switched ON, the blade tried to move from position A to position B inside a watermelon, as shown in figures 3.15. In figure 3.15 only one blade is shown. There were a total of three blades placed 120 degrees apart. The position of the other two blades (not shown in figure 3.15) were at the small circles drawn at 120 degrees apart. In figure 3.15 'A' is the position of the blade when the shaft was at rest and 'B' was the position of the blade when shaft started to rotate. This outward movement of the blade resulted in an impact when the blade hit the red watermelon flesh. This process was repeated several times in every revolution, and each time a small amount of flesh was sheared and juice was formed. Figure 3.16 shows the general path traveled by a blade while penetrating the red watermelon flesh. Point A was the starting point of the penetration and point B was its end point. At the end of the impact, the blade was dislodged out of the red watermelon flesh by the spinning shaft. The impacts, generated by all three blades, sheared the entire red watermelon flesh into juice in two to three minutes at 1200 rpm.

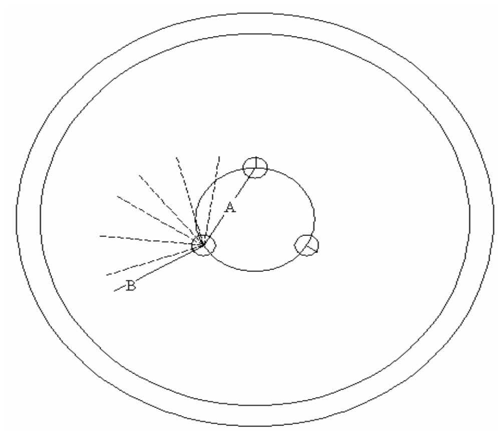


Figure 3.15 Schematic diagram showing path traced by one of the three blades while opening from rest (the other two blades are not shown in the figure).

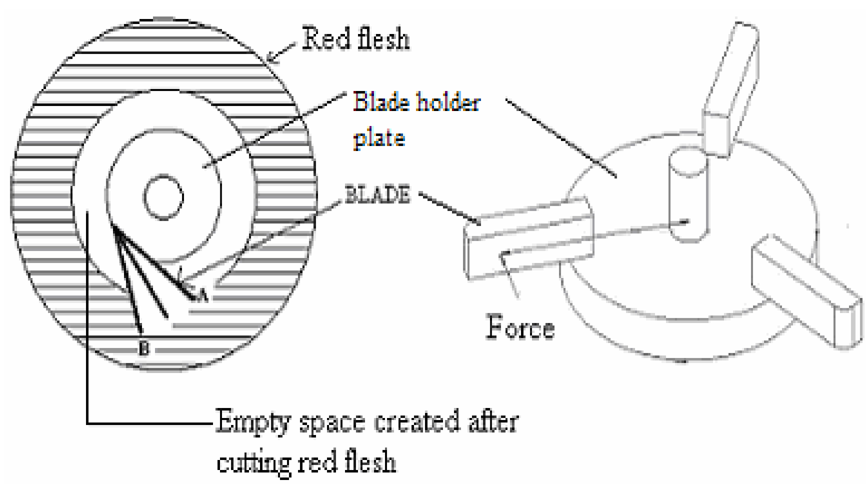


Figure 3.16: Schematic diagram showing start and end of impact of one of the three blades.

4 RESULTS AND DISCUSSION

4.1 SUMMARY

This chapter has four main parts. Section 4.2 reports results of twelve shear force test on watermelon samples (includes red watermelon flesh and rind). Section 4.3 reports experimental results of 3-blade assembly. Section 4.4 lists the benefits associated with the device discussed in this thesis. Section 4.5 suggests future work required to improve 3-blade assembly.

4.2 SHEAR FORCE LAB TEST RESULT

4.2.1 SHEAR STRENGTH OF WATERMELON

The load cell of the Instron machine was calibrated and it was found that the minimum force the load cell could measure was 0.98 N (refer to appendix B for graphs at different calibration load). Refer to appendix C for a graph of shear force measured for twelve watermelon samples (six samples from region I and six samples from region II) at three different crosshead speeds and two different blade configurations. Table 4.1 shows the maximum shear stress and shear force measured in the twelve samples. All six watermelons were 200 mm in diameter (approximately) and spherical in shape. Spatial distribution showed that shear strength was the least at the center and increased towards the rind (for graphs refer to appendix D). It was impossible to test all cultivars of watermelon in this research. Therefore, the minimum and maximum values of shear stress measured in this research could not be generalized to all watermelon cultivars.

Table 4.1: Maximum shear force reading

Blade type	Sample	Crosshead speed (mm/min)	Maximum shear force (N)	Maximum shear stress (N/mm^2)
Sharp edge	Red flesh	1270	7.5	0.0075
		635	11	0.011
		0.001	14	0.014
	Rind	1270	75	0.075
		635	110	0.11
		0.001	170	0.17
Blunt edge	Red flesh	1270	9.5	0.009
		635	11	0.011
		0.001	13	0.013
	Rind	1270	90	0.09
		635	110	0.11
		0.001	120	0.12

As shown in table 4.1, the maximum shear stress ranged from 0.0075-0.014 N/mm^2 in red watermelon flesh and from 0.075-0.17 N/mm^2 in the rind.

4.3 3-BLADE CUTTER RESULT

4.3.1 SATISFACTORY CUTTING SPEED

The satisfactory rotational speed of cutting red watermelon flesh was approximately 1200 rpm (Satisfactory cutting speed was determined as per the criteria discussed in section 3.3.3). The rind was cut at a rotational speed of about 2000 rpm (approximately). The minimum rotational speed needed to cut red watermelon flesh was 400-500 rpm. Figure 4.1 shows picture of a watermelon that was cut at 1200 rpm using the 3-blade assembly.

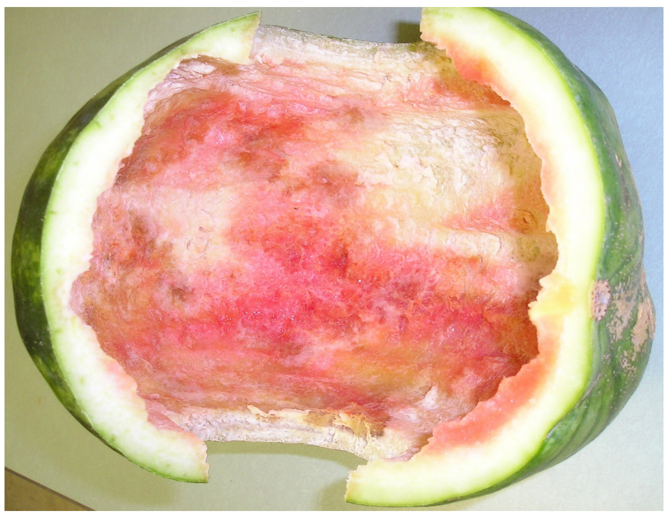


Figure 4.1: Picture of watermelon cut at 1200 rpm using the 3-blade assembly.

It was found that speed was an important factor for cutting. If the speed was below 400-500 rpm, no cutting took place. At higher speed, the rind was cut quicker, because the increase in initial rotational speed resulted in an increase in acceleration and a corresponding increase of the impact force.

Section 3.3.8.1 and 3.3.8.2 of chapter 3 shows that the impact force depended on the mass of the blade. It can be inferred that at a rotational speed of 1200 rpm, if the mass of each blade was increased, then the impact force generated could have been greater and the rate of cutting could have been higher.

It can be further inferred that if the strength of the red watermelon flesh or rind changed with different cultivars of watermelon, the force required to shear the watermelon flesh could also change. In order to compensate for any change in shear strength, a variable speed motor would be required. The maximum speed of the motor could be set for the maximum shear force required. Therefore any individual using such equipment should perform preliminary tests to find the satisfactory cutting speed.

4.3.2 CURRENT DRAWN BY MOTOR

Voltage at the start of cutting the red watermelon flesh was 15.88 V. After cutting the entire red watermelon flesh, the voltage was 15.7 V. Thus average voltage was 15.79 V and was used in all the related calculations. To overcome internal resistance of the motor and rotate the 3-blade assembly at 1200 rpm, the motor drew an average current of 4.5 A at 15.79 V. The sum of the current drawn by the motor to overcome its internal resistance, to rotate 3-blade assembly, and to cut red watermelon flesh was 5.2 A at 15.79 V. Thus the power required to cut only red watermelon flesh was 11.05 W. Refer to appendix E for the calculation.

4.3.3 IMPACT FORCE CALCULATION

The experimental impact force of each blade measured using the Instron machine was 4 N. To view a graphical output of this test, please refer to appendix F. The total number of impacts per revolution using the method described by McCutchen (2000) was calculated to be 10 at 1200 rpm. Refer to appendix G for the calculation.

4.3.4 SHEAR AREA OF BLADE IN IMPACT FORCE

The shear stress generated by each blade would be the impact force of each blade (4 N, from 4.3.3) divided by area of blade in contact with red portion while cutting the red portion (this is the portion of the blade at tip of the blade). Practically this area could not be measured. The total area of blade was 50 mm x 19 mm = 950 mm^2 (refer figure 3.5 for dimension). Only a part of this area, towards the tip, of the each blade cut the red portion in every revolution. From section 4.2.1 the maximum shear stress to cut red portion was 0.014 N/mm^2. If we divide 4 N by 0.014 N/mm^2 the area of cross-section would be 285 mm^2. Thus approximately 30 % (285*100/950) of the blade area at the tip was used to cut the red portion in each revolution.

4.4 BENEFITS

1. The equipment can reduce the handling cost and time during harvesting.
    a. It can reduce the time and cost involved in transporting watermelon from the field to the processing factory.
    b. Waste products (rind, seeds, and spilled juice) could be disposed by leaving them in the field, or they could be selectively recovered for other uses.
2. The juice obtained would be free from seeds. This would reduce the time and cost involved in separating seeds from the juice.
3. The proposed watermelon juice extraction device had fewer moving parts compared to existing equipment, and no electronic parts like sensors were required. Thus it could be easily maintained and would have a low initial cost.

4. The equipment could be used as a step in the process to harvest lycopene from cull watermelons left in the field.
5. The leftover rind in the field could be crushed and mixed with the soil to replenish some of the minerals lost by the soil in the watermelon growing process.

4.5 SUGGESTIONS FOR FUTURE RESEARCH

A pumping system needs to be designed to easily pump out the juice from inside the watermelon to a storage tank. The storage tank could be portable and it could house the pump and filters. The filters should remove the seeds and water from the juice.

At present all the experiments were conducted with aluminum blades on the 3-blade assembly, if a flexible material can be used instead of aluminum then a larger cutting area inside the watermelon can be covered. The material property should be such that it should cut only the red portion inside the watermelon and not the rind. The length of this blade should be equal or more than maximum diameter of the watermelon to be cut. This material should bend if it hit the rind portion. In this way all size and shape of watermelon can be cut by single blade.

In the present 3-blade assembly any person operating the device manually pulls or pushes the cylinder to engage with the main shaft, instead an electromagnetic clutch can be used to engage and disengage the cylinder and main shaft.

5 CONCLUSION

Watermelon juice is a major natural source of lycopene, an important nutraceutical known for its potential effectiveness in preventing cancer and cardiovascular disease. The present methods of watermelon juice extraction from watermelon fruit rely on a process of extraction with centralized machinery, followed by separation steps which remove contaminants and undesirable materials from the juice. A faster, safer, low-cost method was desired to extract watermelon juice from the fruit left in the field (unharvested).

This research was an attempt to develop a device that could be used to extract juice from watermelon lying in the field. The main goal was to develop a handheld extractor having a set of blades to shear the red watermelon flesh into juice. The juice could then be pumped out of the watermelon. The system should be easy to operate and handle, and may require an AC or DC power source (or both). The operator could carry the equipment or use a vehicle to bring the equipment into the field and to each watermelon. Juice could be stored in a portable container. Seeds could be separated from the juice using inline sieves. Worn-out blades could be easily and quickly replaced

The first objective was to study shear strength of watermelon fruits. The maximum shear stress recorded in the rind section is 0.17 N/mm^2 and in the red portion near the rind portion was 0.014 N/mm^2. Thus the shear stress generated by the 3-blade assembly should be less than 0.17 N/mm^2 and more than 0.014 N/mm^2. The second objective was to develop a mechanism to shear red watermelon flesh and turn it into juice without crushing the rind. The mechanism was required to bore a hole through the rind, to allow the cutting blades to enter the watermelon through the hole and shear the red watermelon flesh. The blades should not rotate before entering the watermelon to ensure their easy entry into the watermelon, and to prevent injury to the operator from the blades. Such a device was designed and tested as described in section 3.3.2 and 4.3. The satisfactory cutting speed to cut the red portion by 3-blade assembly was approximately 1200 rpm. The rind got cut at approximately 2000 rpm.

The following conclusions were drawn from the results of the study:

1. Shear strength of red watermelon flesh was not spatially constant throughout the interior of the watermelon. It was lower in the center and increased towards the rind.
2. Motor rotational speed was an important factor in cutting. Higher speeds (in the range tested) resulted in a higher cutting rate.
3. An increase in blade mass resulted in an increase in the impact force of the blade.
4. Impact force depended on the combination of the speed and mass of the blade.
5. Operating the blade at very high speed (above 2000 rpm) could cut holes in the rind.

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APPENDIX A – PART & ASSEMBLY DRAWING OF PROTOTYPE 3-BLADE ASSEMBLY

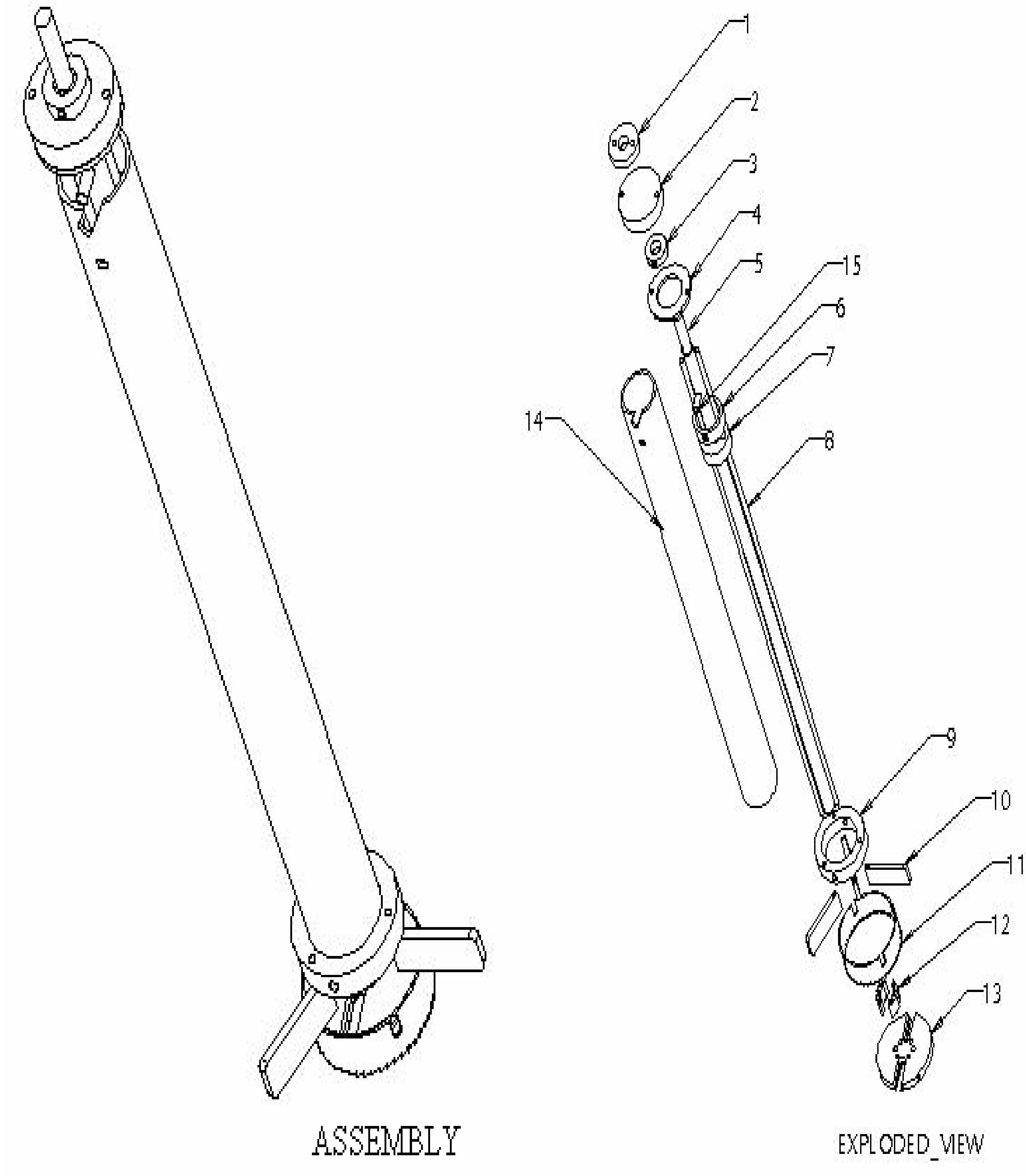

Figure A1: Orthogonal drawing and exploded view of prototype 3-blade assembly

Table. A1: Bill of materials:

Part Number	Description	Quantity	Material
1	Stopper	1	Aluminum
2	Guide rod holder	1	Polypropylene
3	Guide rod holder sleeve	1	Aluminum
4	Guide rod holder cover	1	Polypropylene
5	Shaft	1	Aluminum
6	Sleeve	1	Aluminum
7	Sleeve for guide rod	1	Polypropylene
8	Guide rod	2	Aluminum
9	Blade holder	1	Aluminum
10	Blade	3	Aluminum
11	Hole saw	1	Mild Steel
12	Hub	2	Mild Steel
13	Slicer	1	Aluminum
14	Cylinder	1	Aluminum
15	Pin	1	Mild Steel

All dimensions are in Inches if figure A2 to A15.

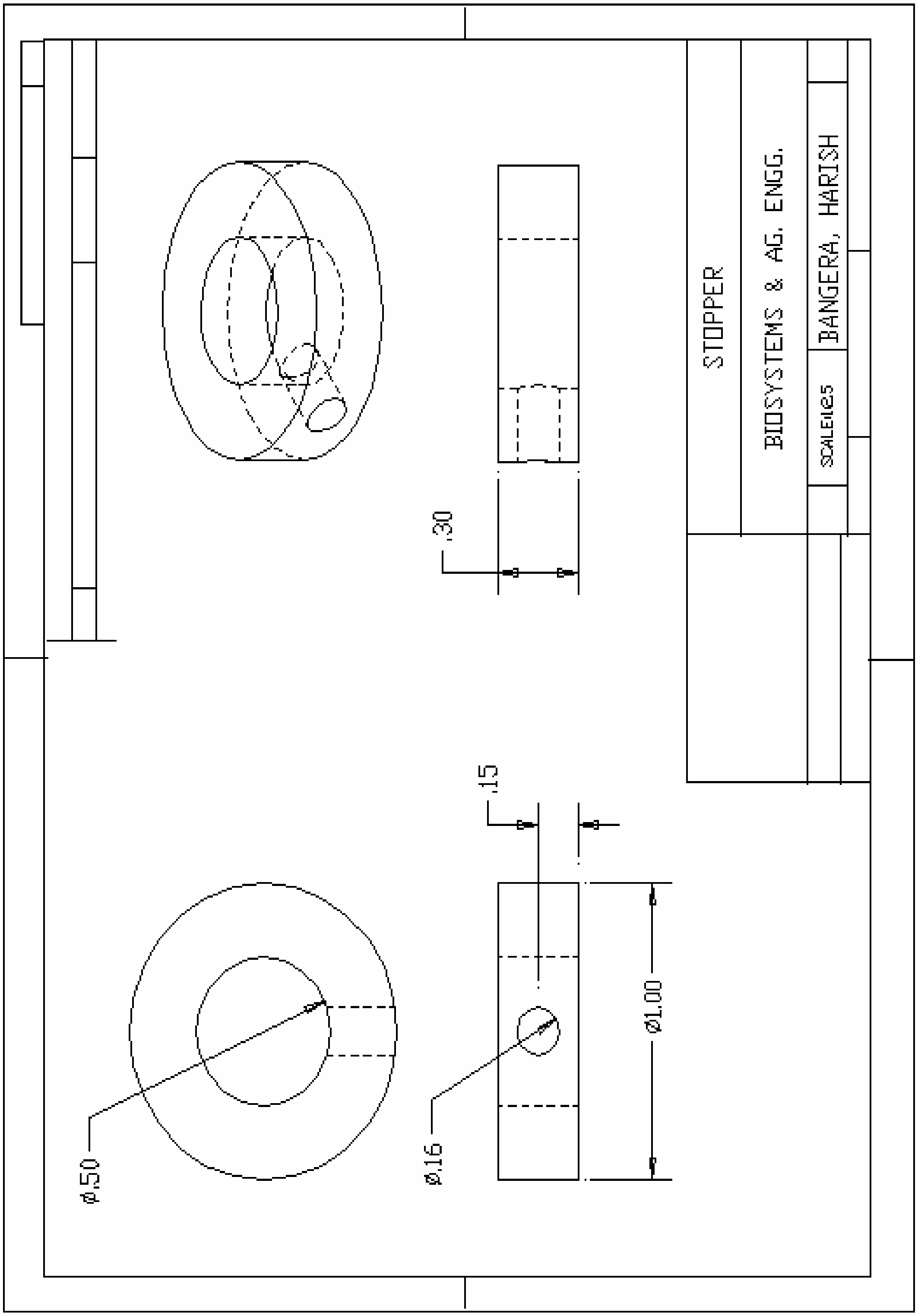

Figure A2: Drawing of part no. 1, Stopper

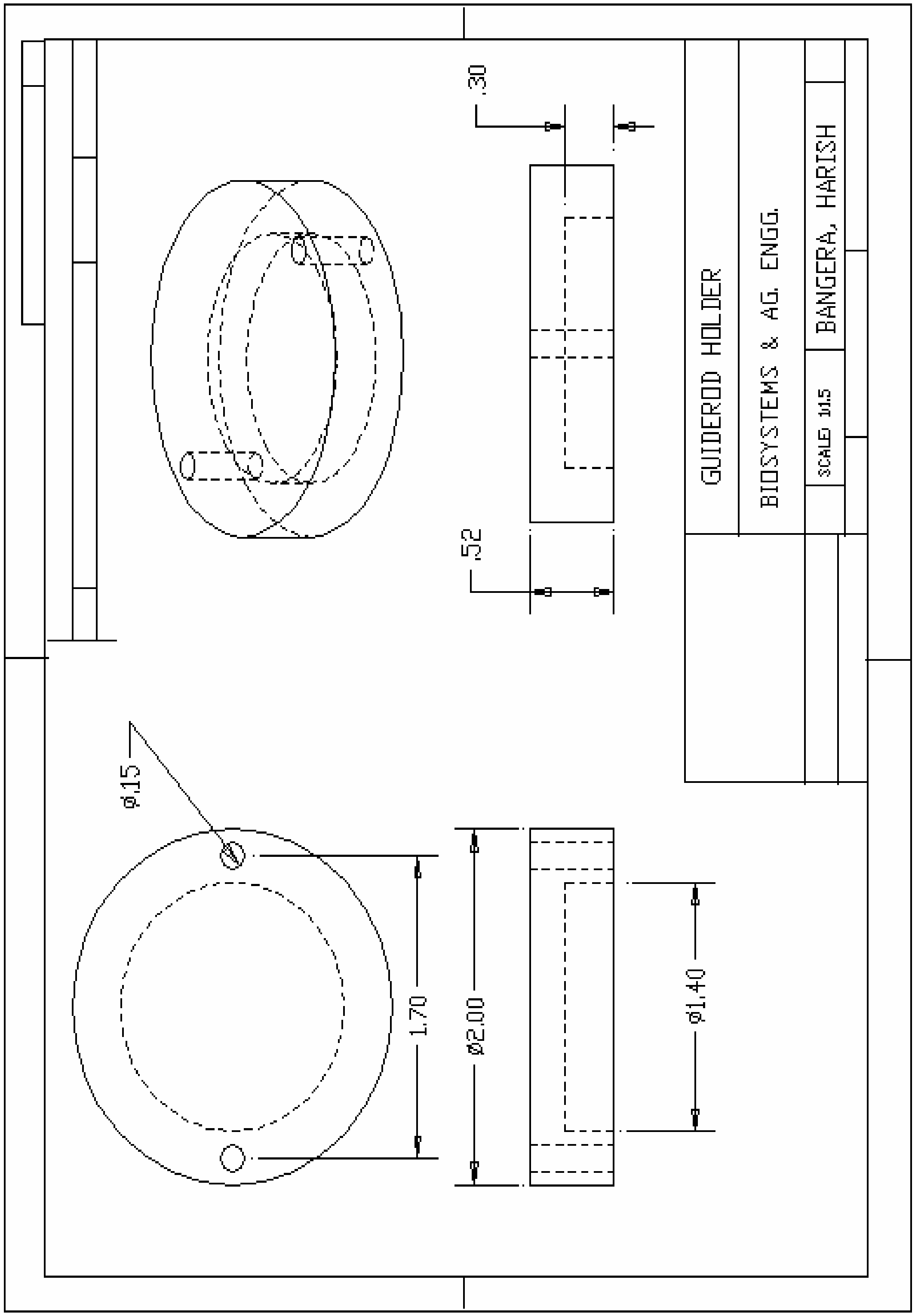

Figure A3: Drawing of part no. 2, Guide rod holder

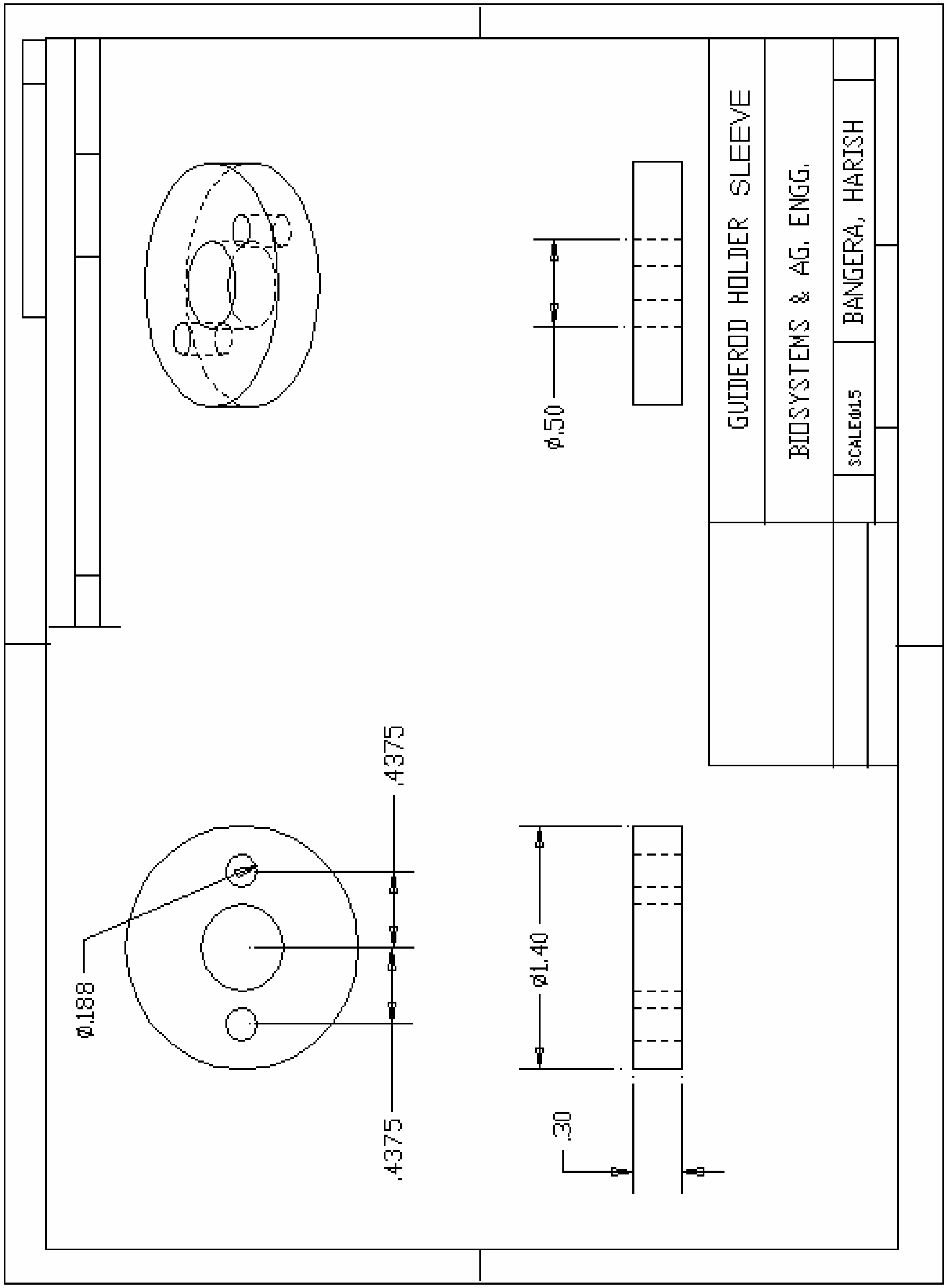

Figure A4: Drawing of part no. 3, Guide rod holder sleeve

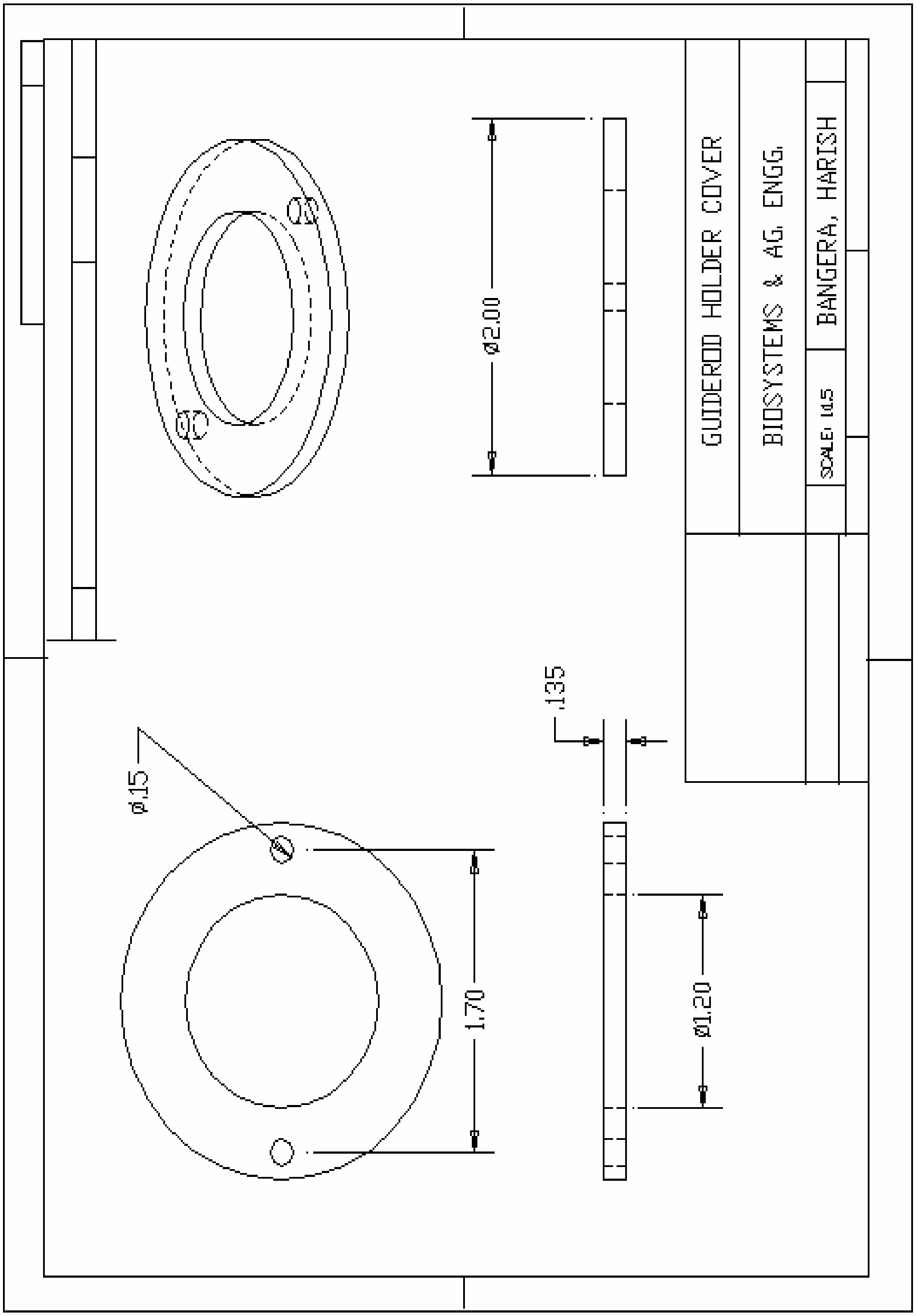

Figure A5: Drawing of part no. 4, Guide rod holder cover

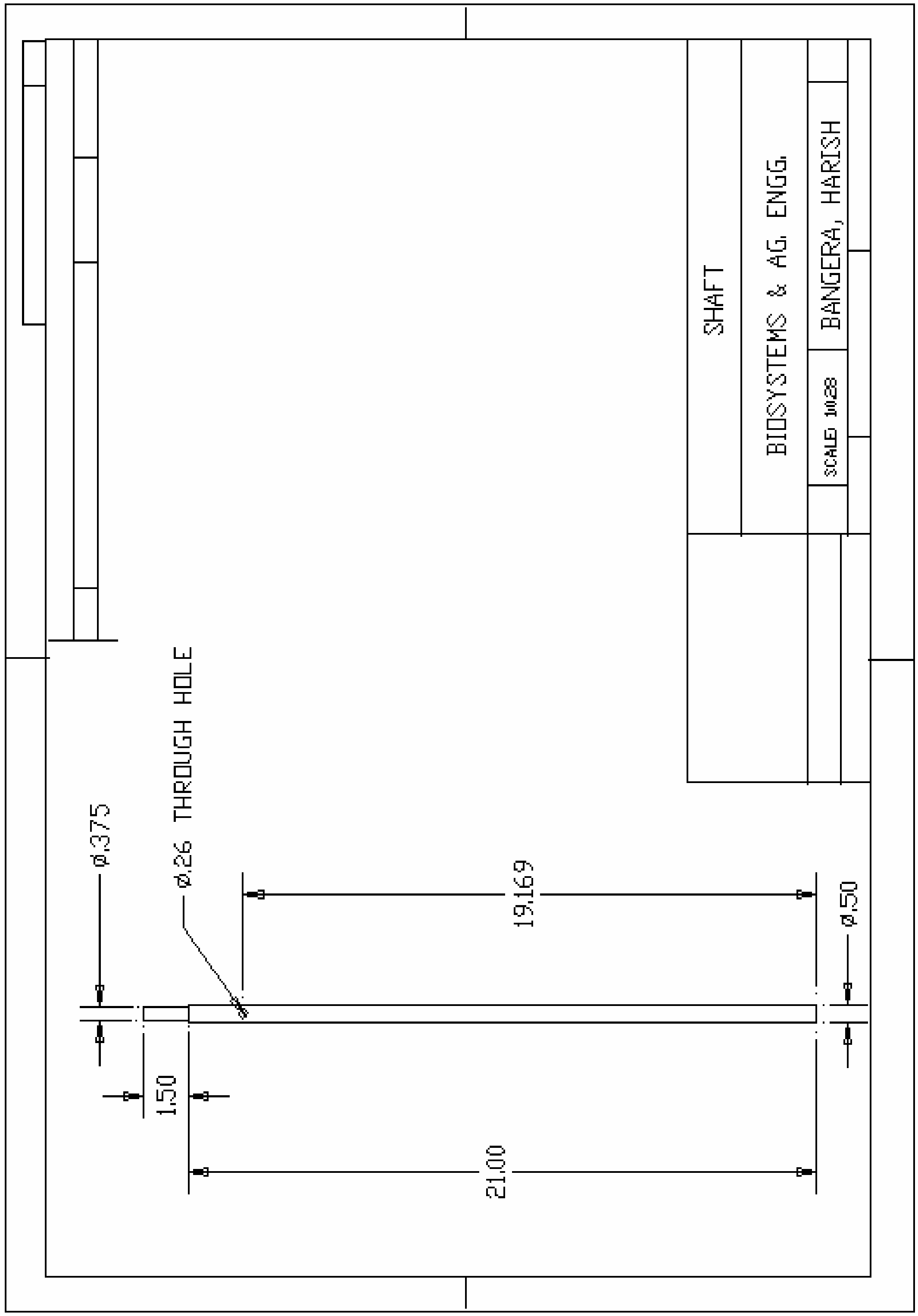

Figure A6: Drawing of part no. 5, Shaft

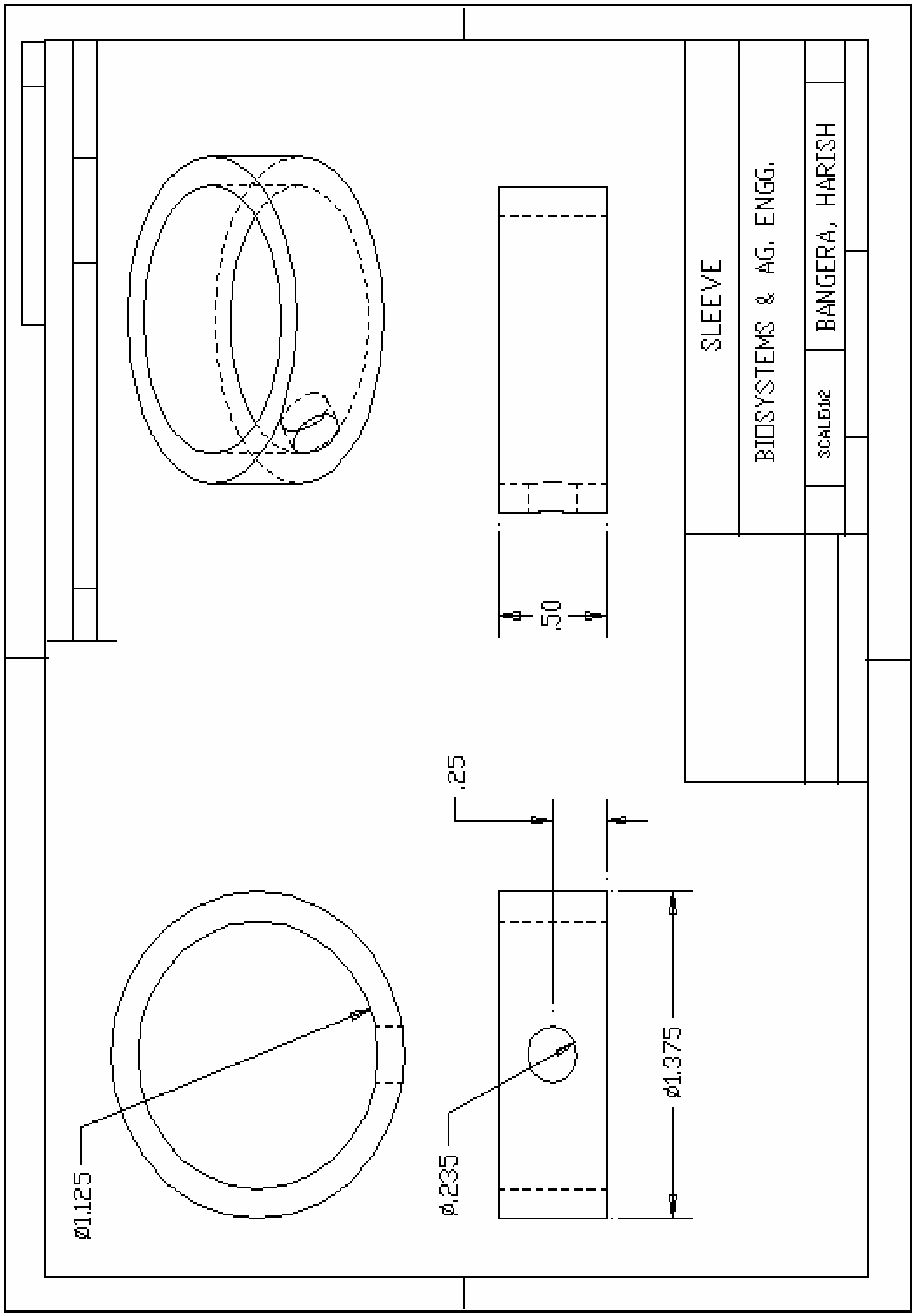

Figure A7: Drawing of part no. 6, Sleeve

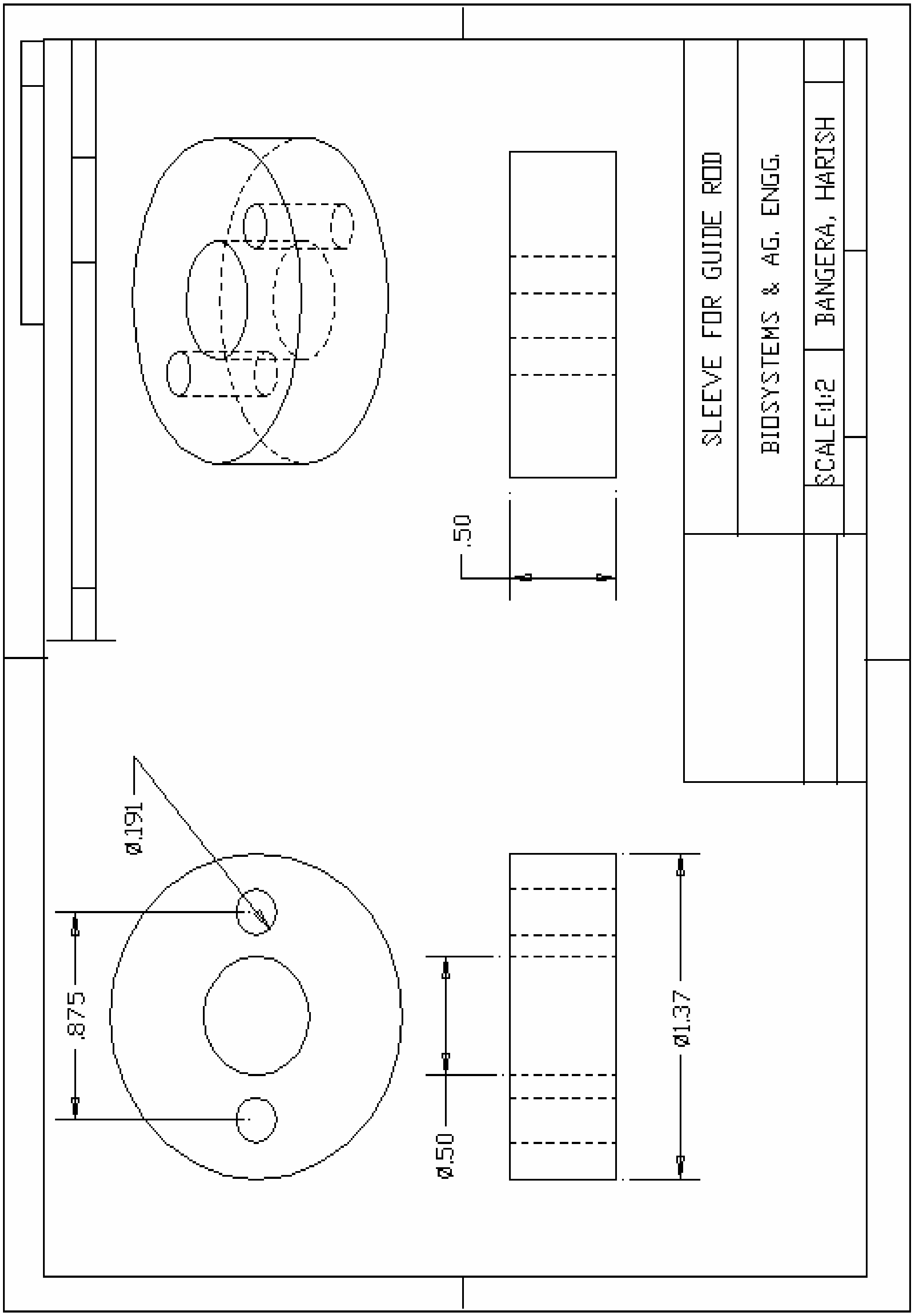

Figure A8: Drawing of part no. 7, Sleeve for guide rod

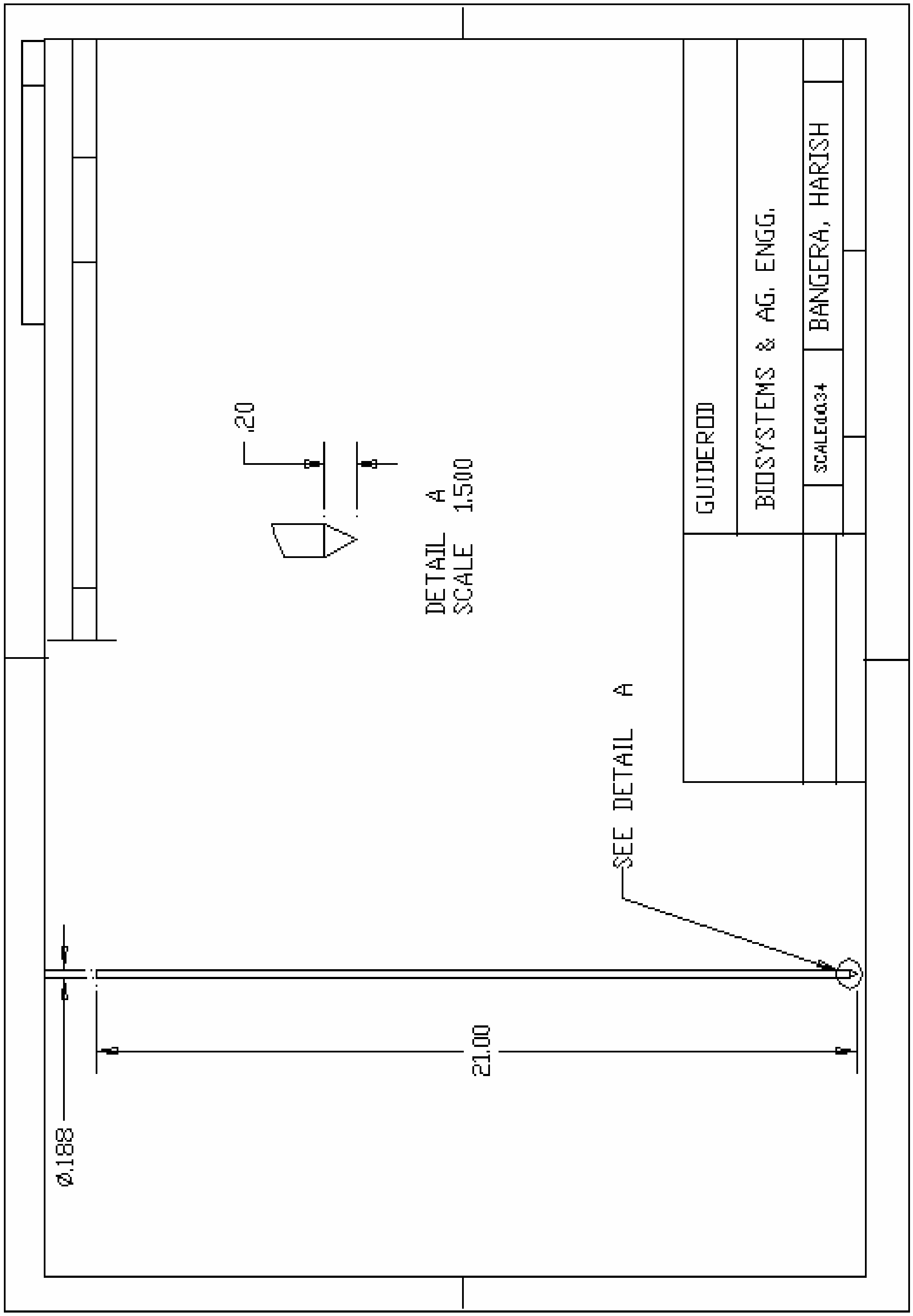

Figure A9: Drawing of part no. 8, Guide rod

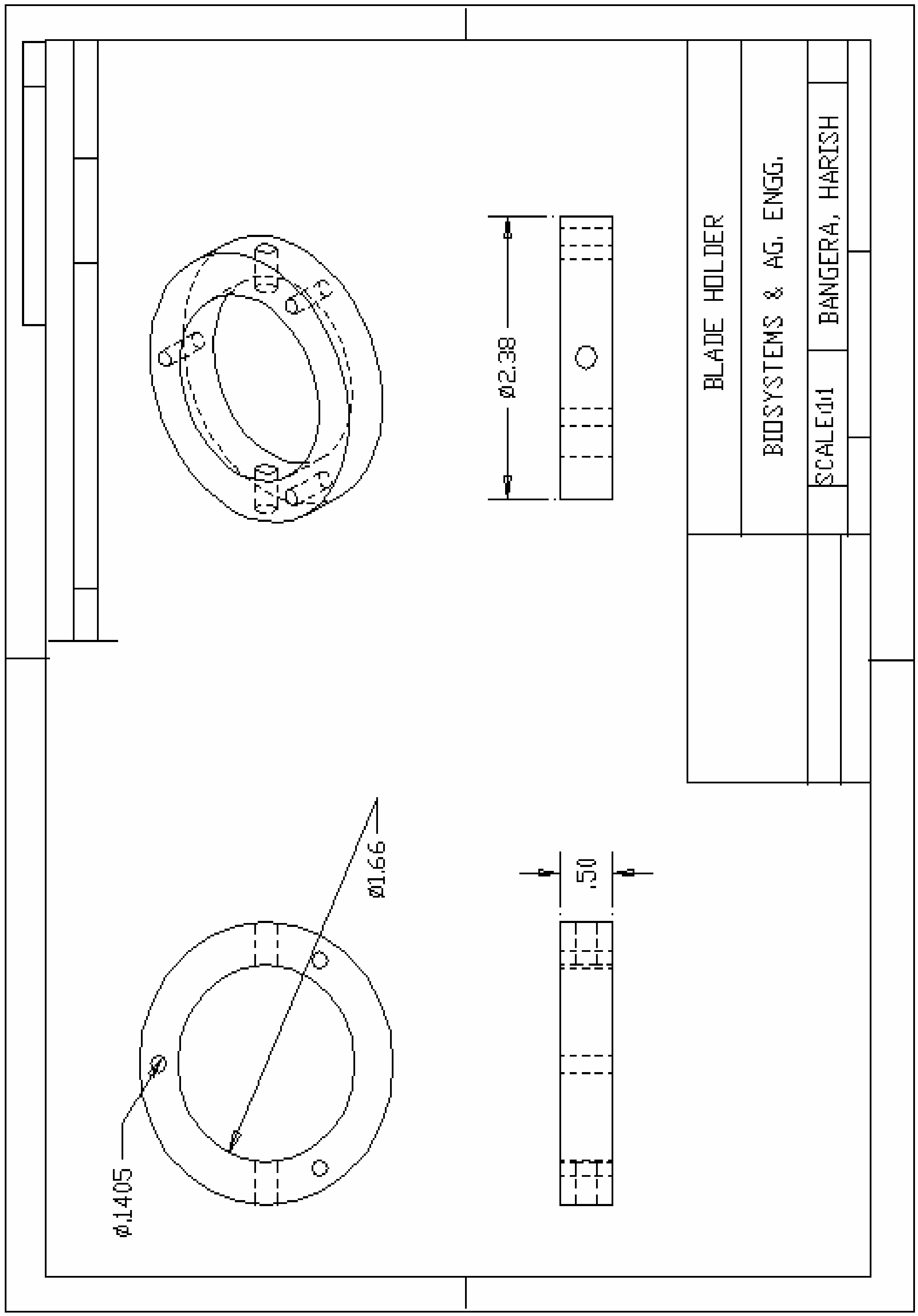

Figure A10: Drawing of part no. 9, Blade holder

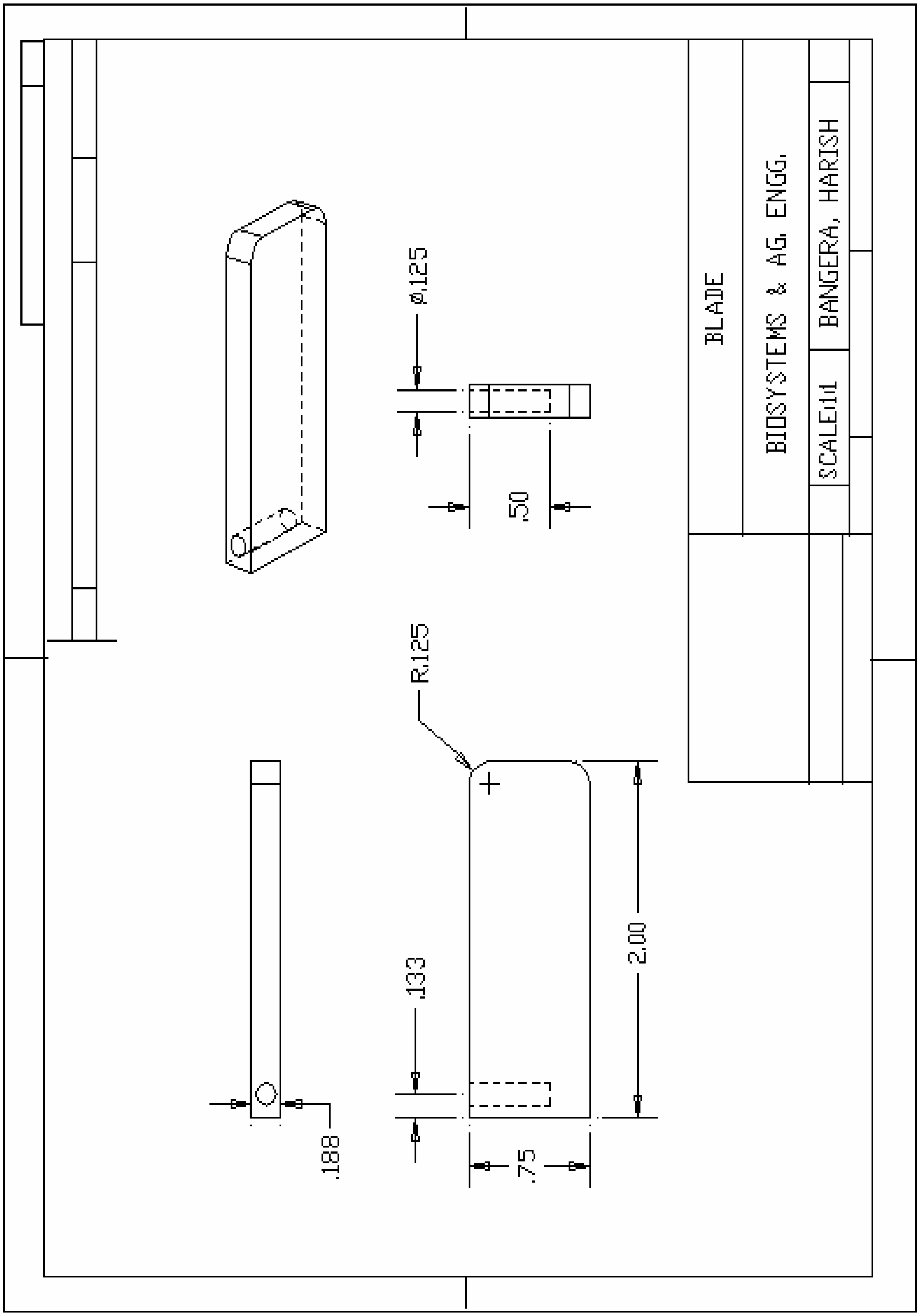

Figure A11: Drawing of part no. 10, Blade

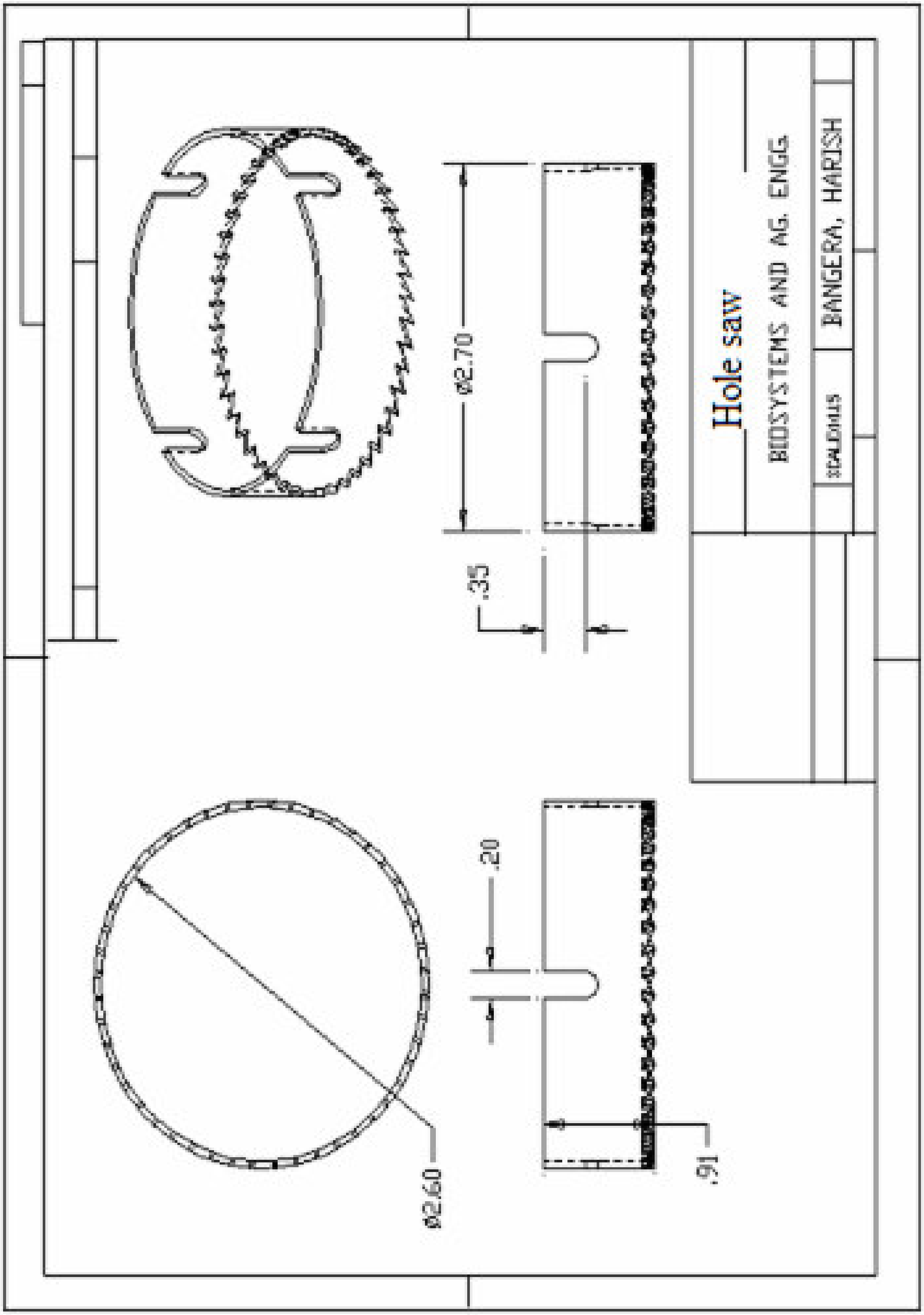

Figure A12: Drawing of part no. 11, Hole saw

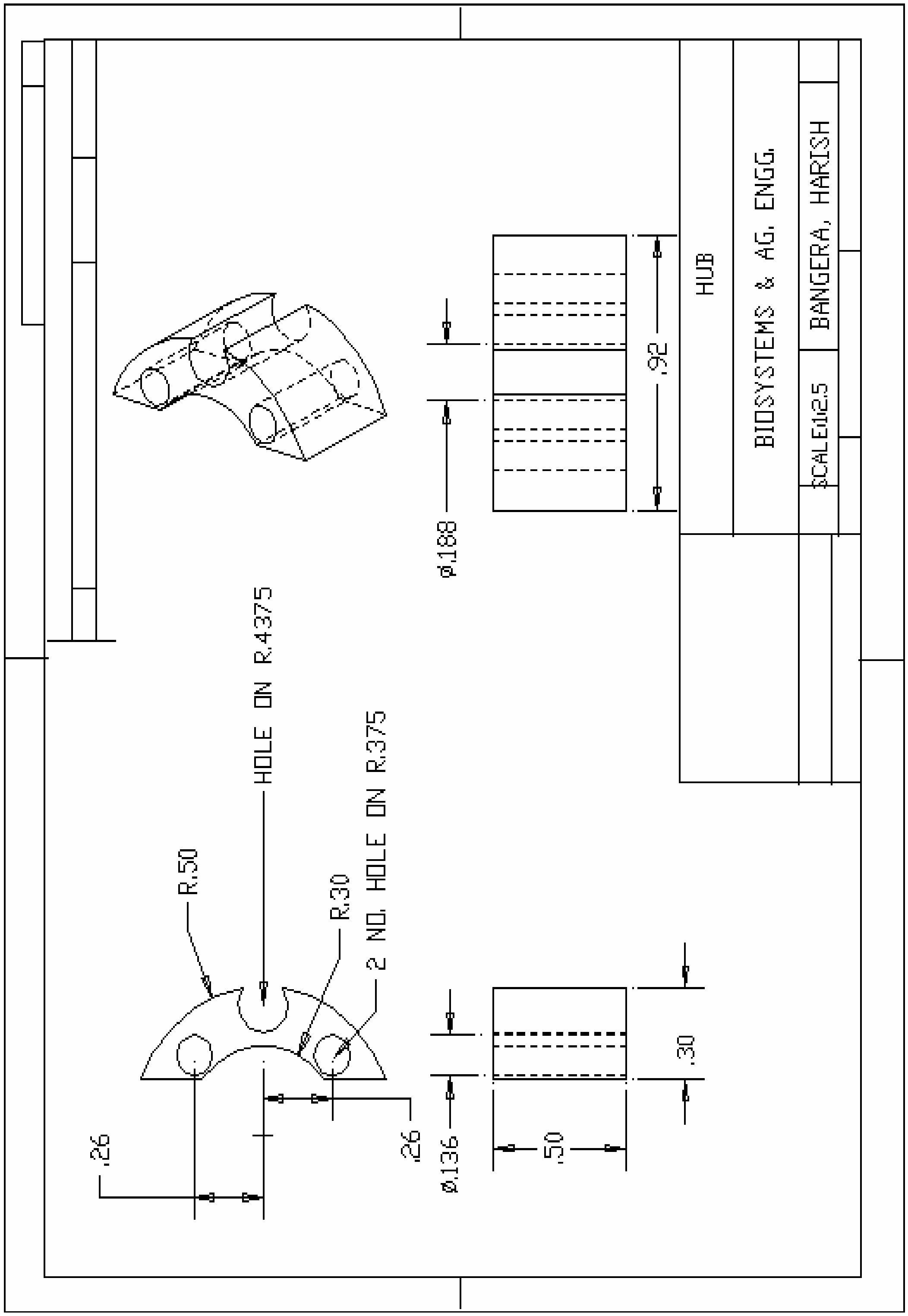

Figure A13: Drawing of part no. 12, Hub

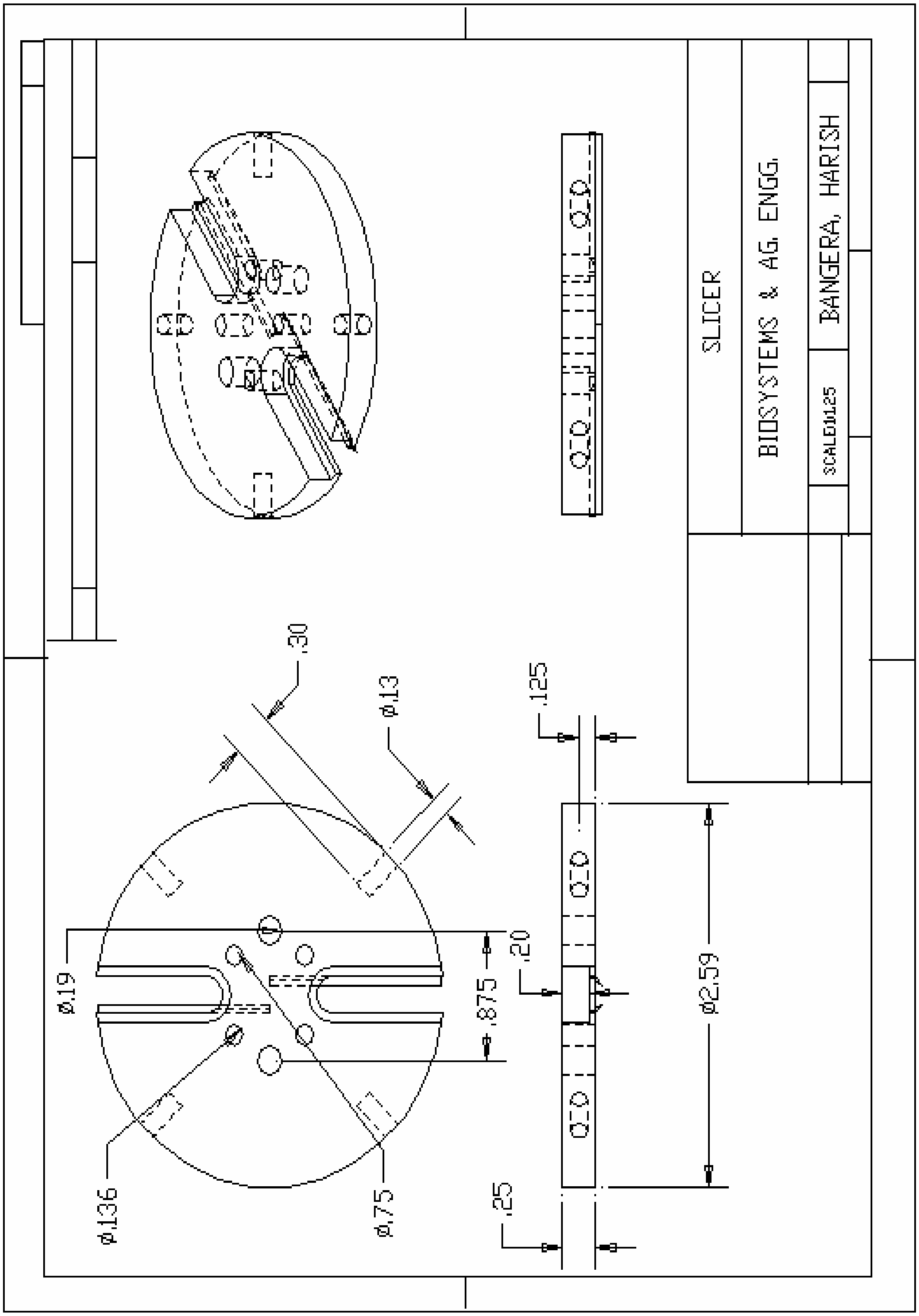

Figure A14: Drawing of part no. 13, Slicer

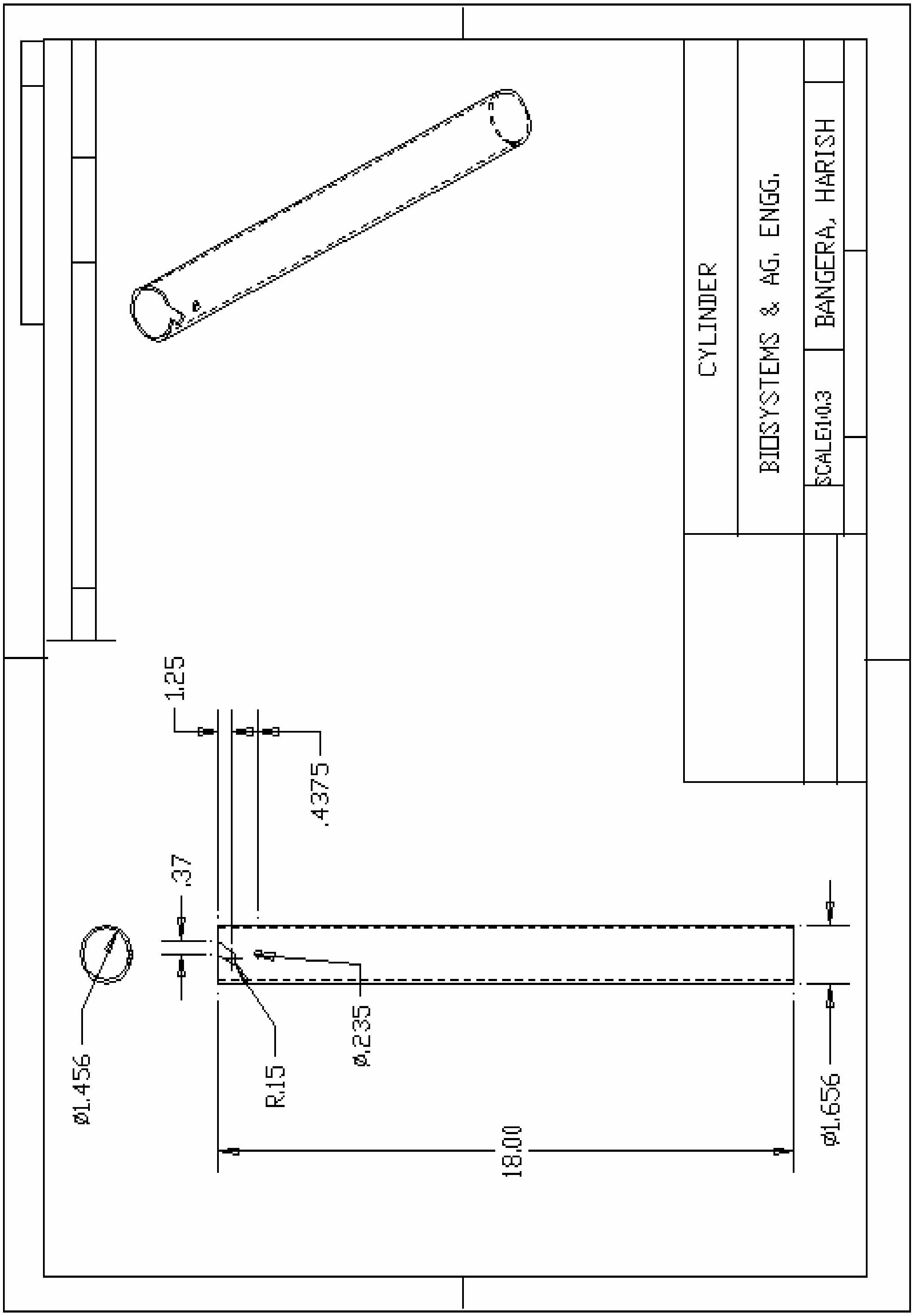

Figure A15: Drawing of part no. 14, Cylinder

APPENDIX B – CALIBRATION OF INSTRON SHEAR TESTING MACHINE

The Instron shear strength measuring machine was calibrated by using standard weights of 5 lbs (22.29 N), 1 lb (4.45 N), 100 gm (0.98 N) and 10 gm (0.09 N) supplied by MTS for calibration. It was observed that for the load of 5 lbs, 1 lb and 100 gm the Instron machine measured accurately, but for the smallest weight of 10 gm the result was very fluctuating. Therefore, it was concluded that this machine can be used to measure forces above 0.981 N. Figures B1 through B4 show the results of Instron machine calibration tests at each of the four loads.

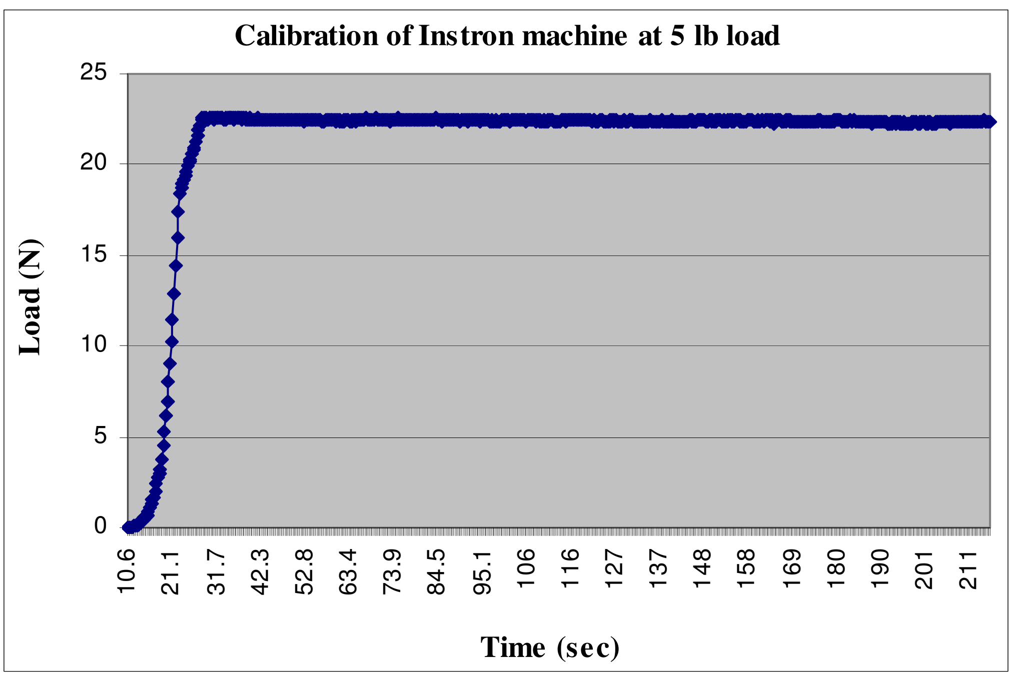

Figure B1: Graph from Instron showing reading at 5 lb load

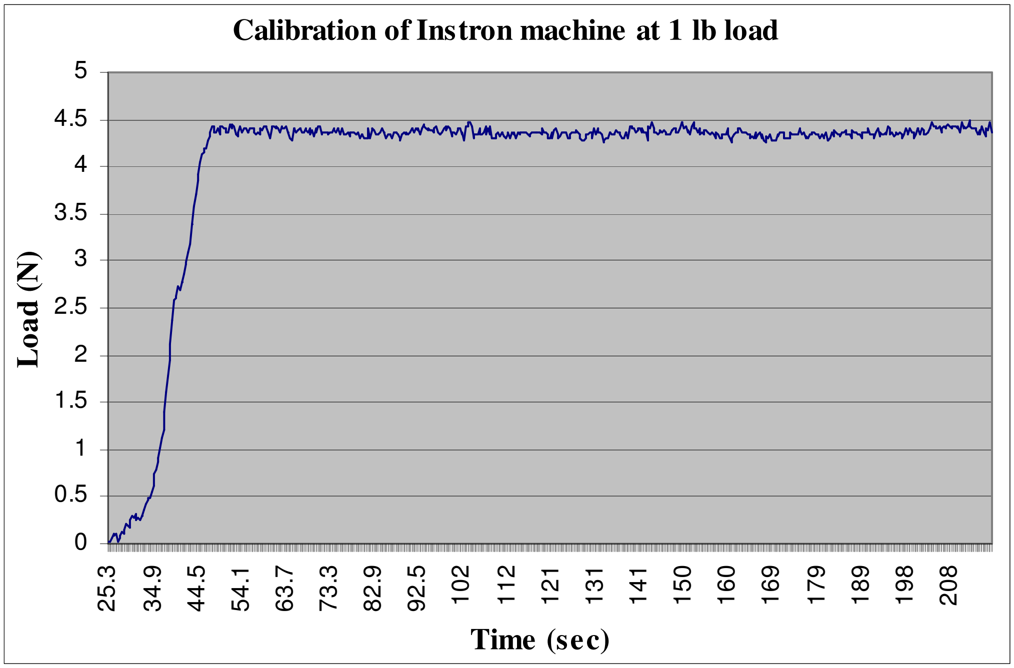

Figure B2: Graph from Instron showing reading at 1 lb load

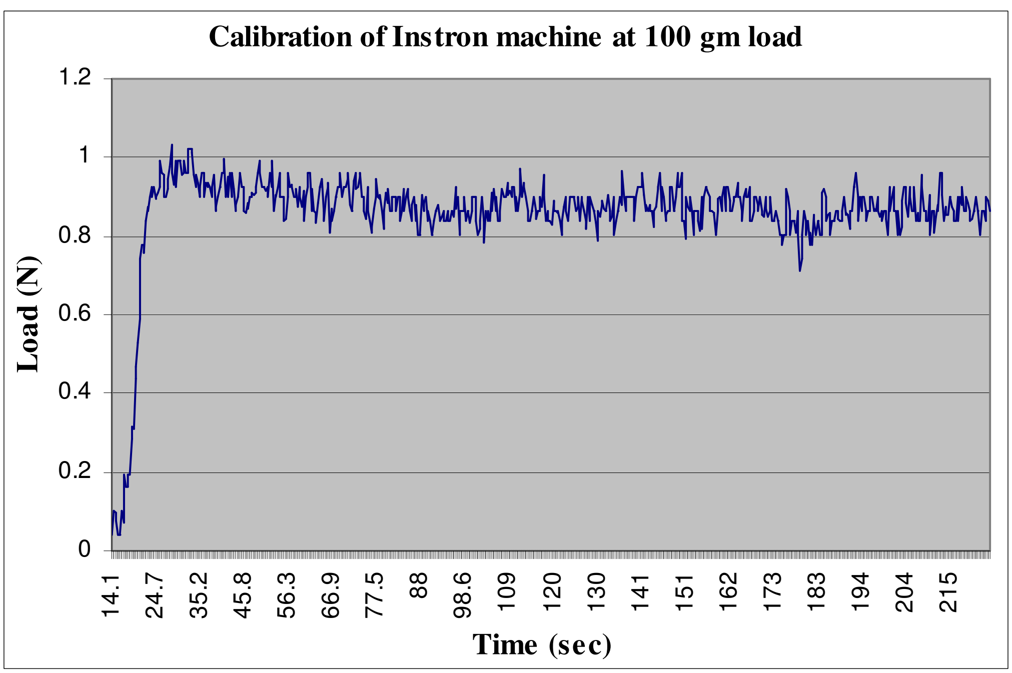

Figure B3: Graph from Instron showing reading at 100 gm load

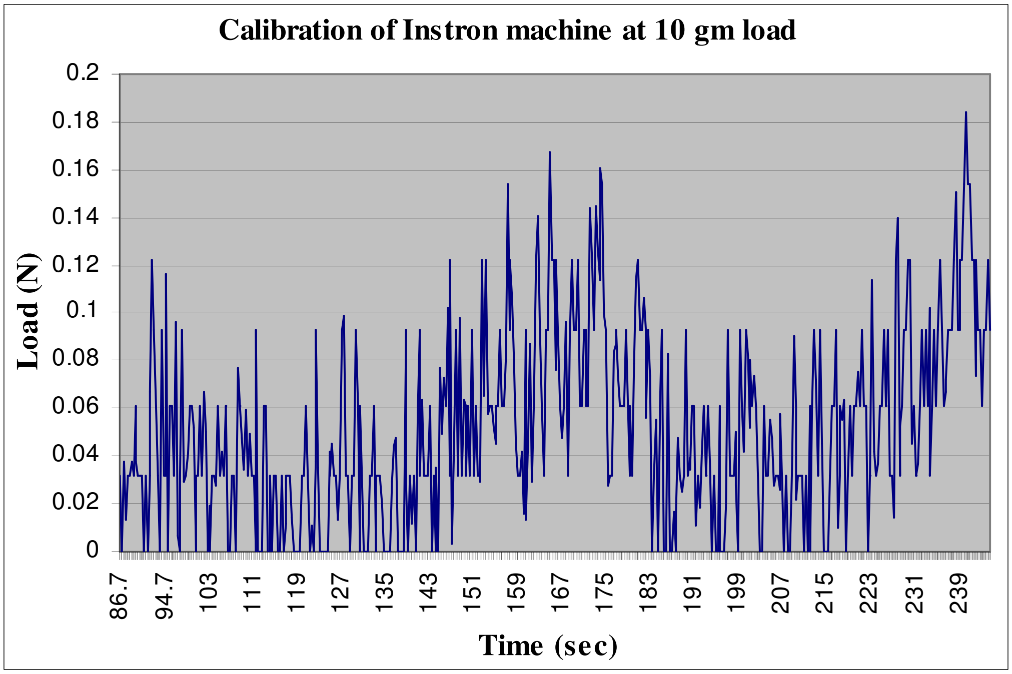

Figure B4: Graph from Instron showing reading at 10 gm load

APPENDIX C– SHEAR STRENGTH OF RED FLESH AND RIND MEASURED BY INSTRON

This appendix contains graphical representations of shear strength plotted against penetration of blade into samples of watermelon flesh and rind (τ = Shear stress).

1. Figure C1, C2, C3 shows shear stress recorded while cutting red flesh (region II of watermelon) by a sharp edge knife at crosshead speed 1270, 635 and 0.001 mm/min respectively.
2. Figure C4, C5, C6 shows shear stress recorded while cutting rind (region I of watermelon) by a sharp edge knife at crosshead speed 1270, 635 and 0.001 mm/min respectively.
3. Figure C7, C8, C9 shows shear stress recorded while cutting red flesh (region II of watermelon) by a blunt edge knife at crosshead speed 1270, 635 and 0.001 mm/min respectively.
4. Figure C10, C11, C12 shows shear stress recorded while cutting rind (region I of watermelon) by a blunt edge knife at crosshead speed 1270, 635 and 0.001 mm/min respectively.
5. Figure C13 shows the shear stress recorded for region I and region II of watermelon at different cross head speed and different blade type. This graph is a consolidated result of graphs used in figures C1 to C12.

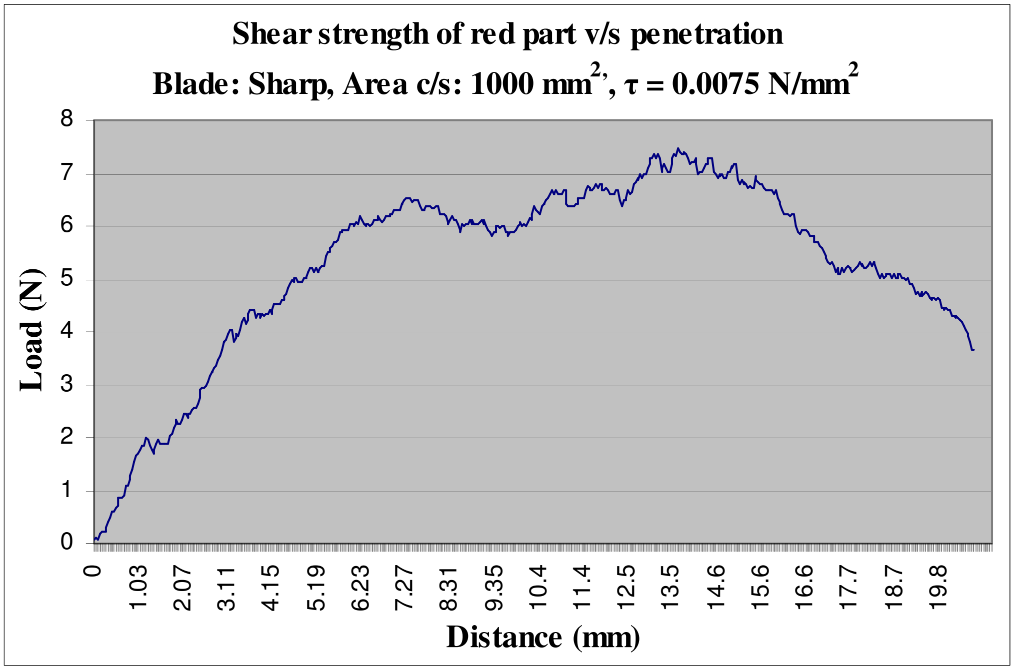

Figure C1: Shear strength of red part (region II of watermelon) @ 1270 mm/min crosshead speed

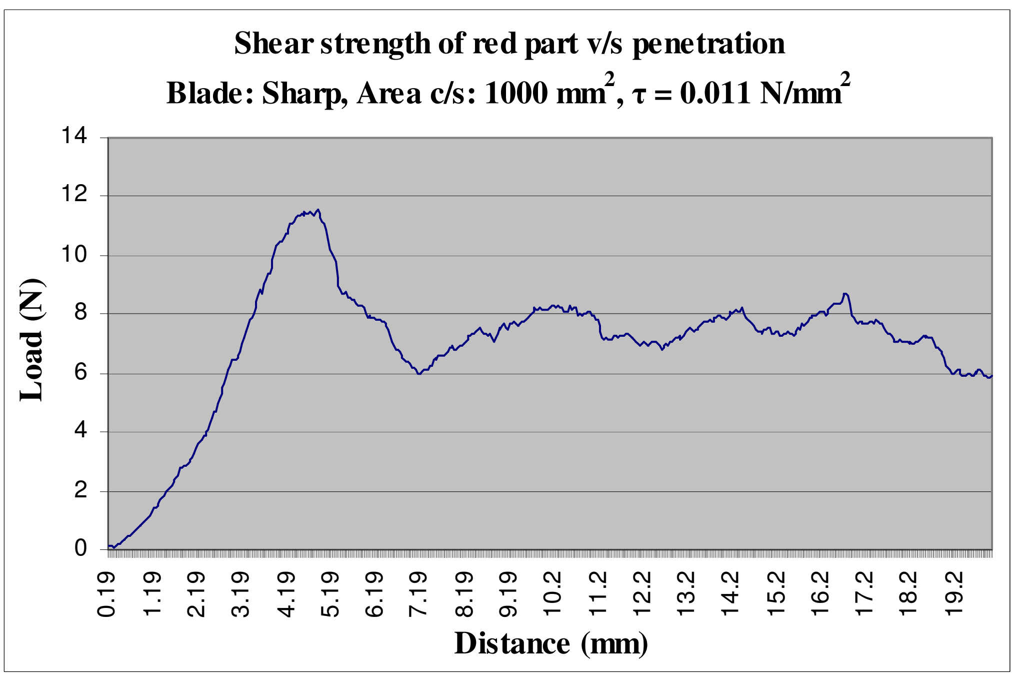

Figure C2: Shear strength of red part (region II of watermelon) @ 635 mm/min crosshead speed

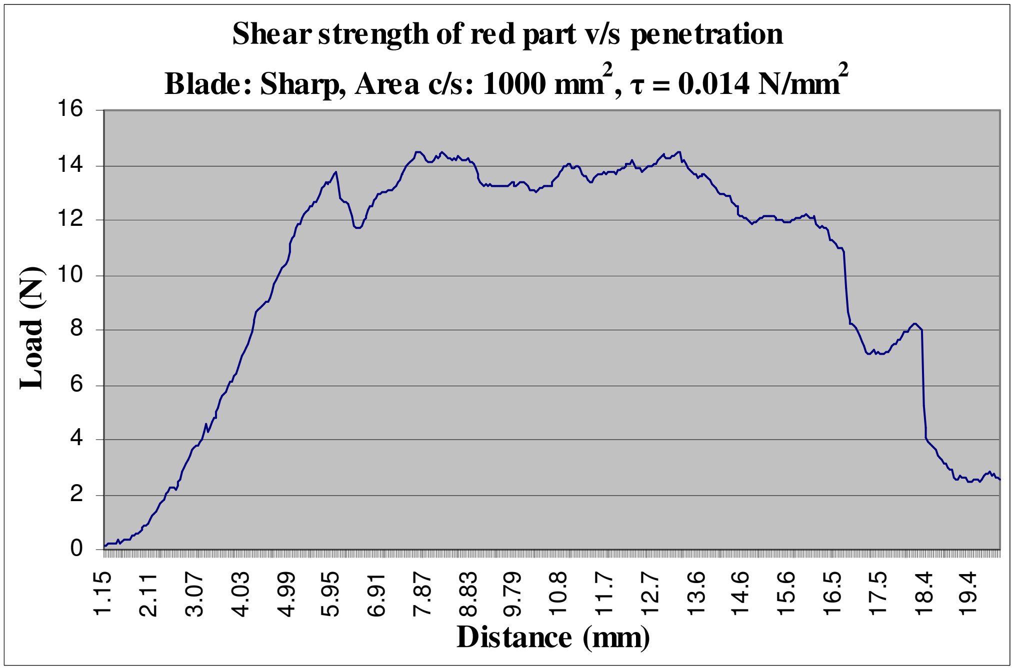

Figure C3: Shear strength of red part (region II of watermelon) @ 0.001 mm/min crosshead speed

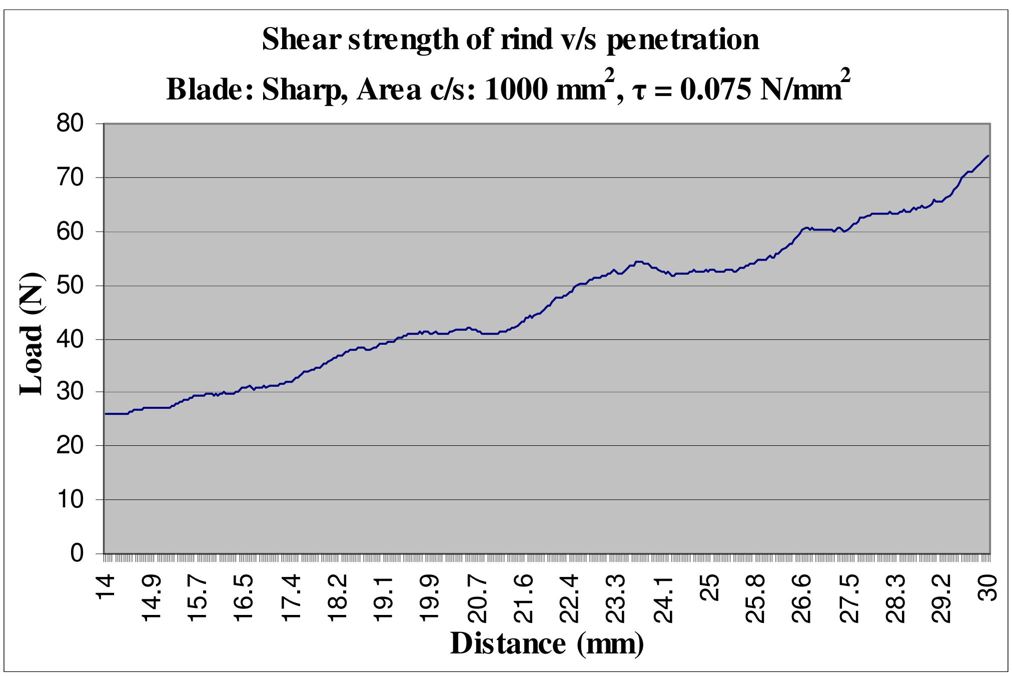

Figure C4: Shear strength of rind (region I of watermelon) @ 1270 mm/min crosshead speed

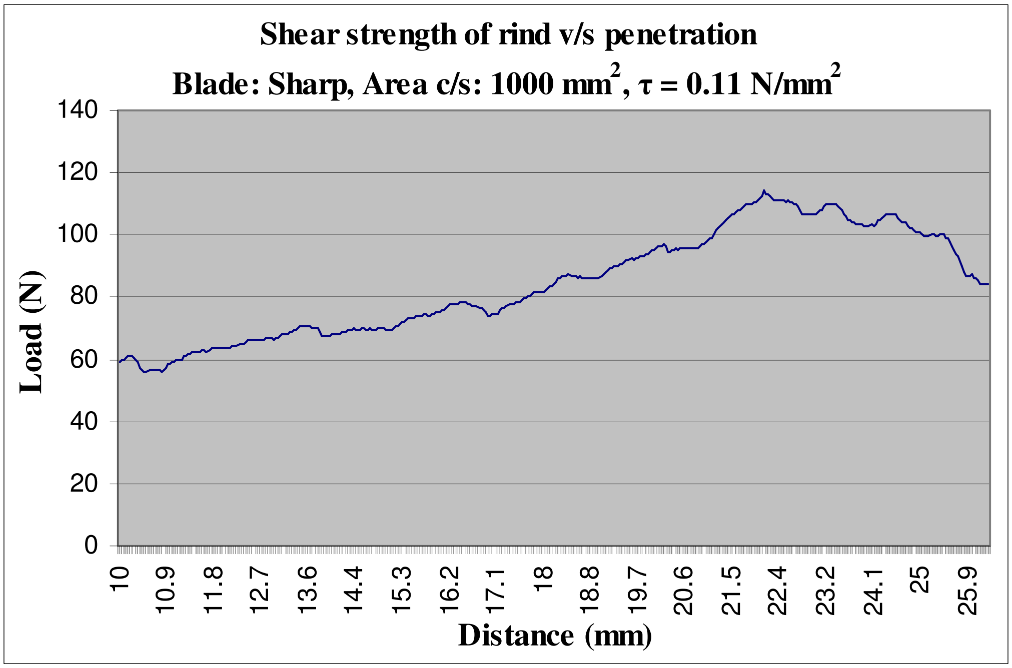

Figure C5: Shear strength of rind (region I of watermelon) @ 635 mm/min crosshead speed

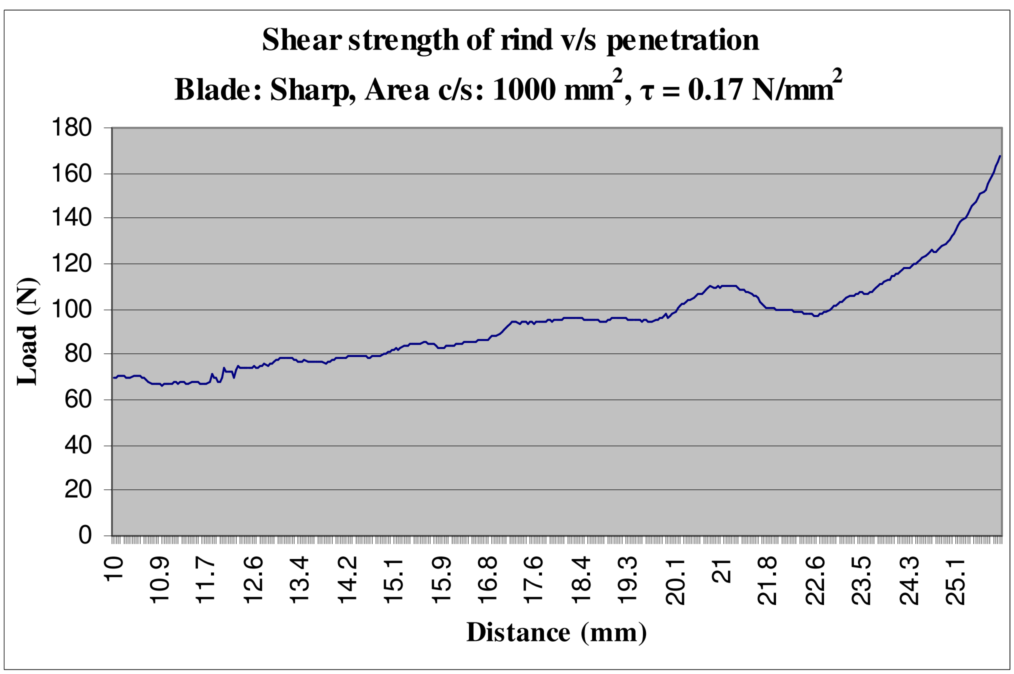

Figure C6: Shear strength of rind (region I of watermelon) @ 0.001 mm/min crosshead speed

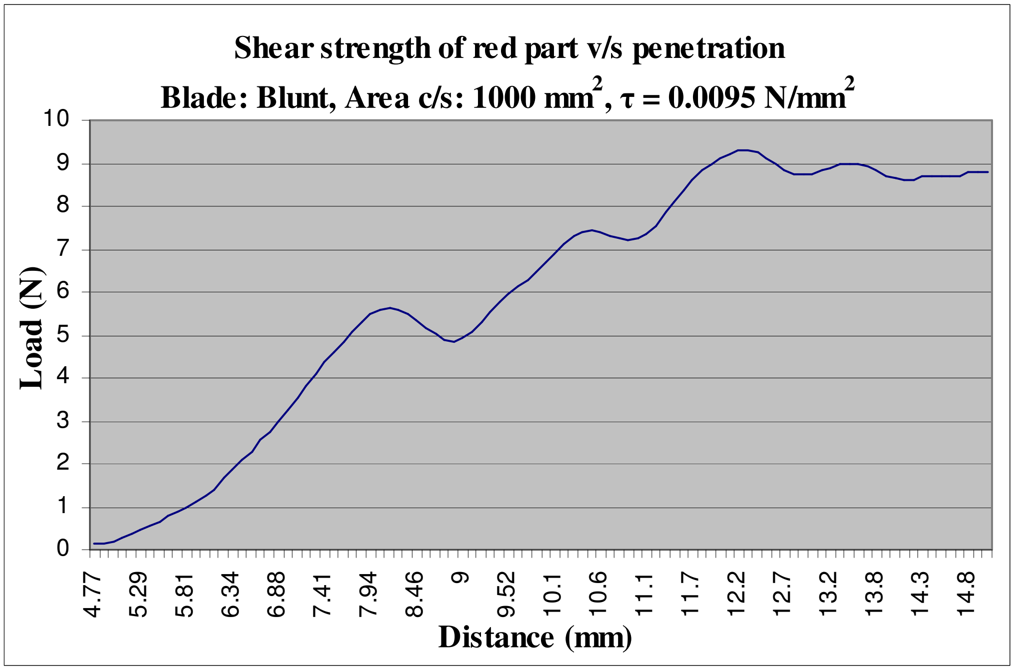

Figure C7: Shear strength of red part (region II of watermelon) @ 1270 mm/min crosshead speed

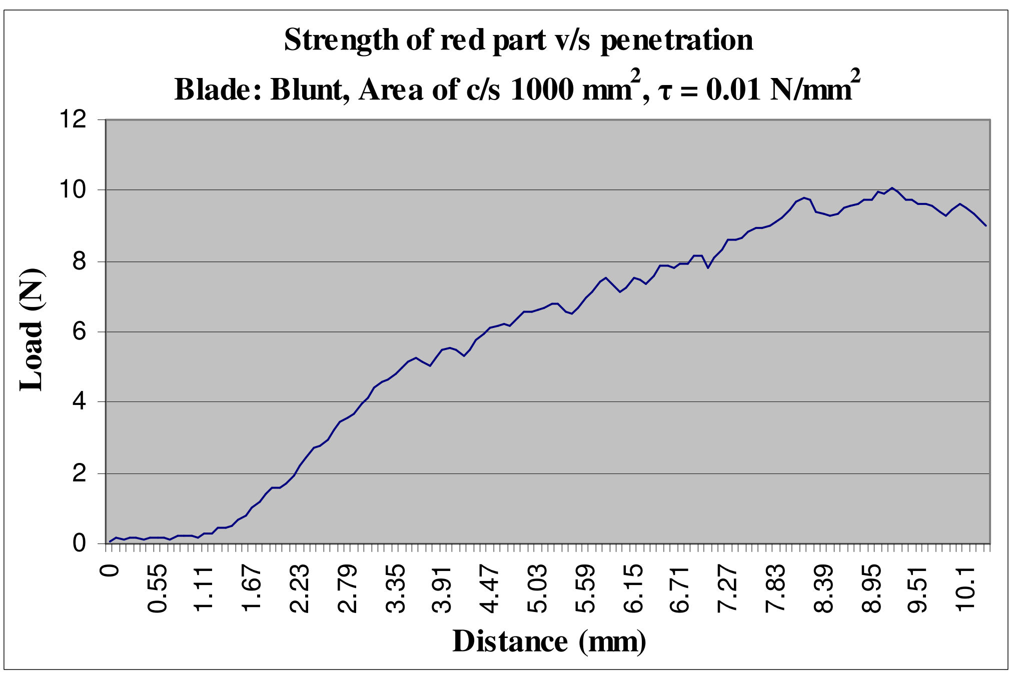

Figure C8: Shear strength of red part (region II of watermelon) @ 635 mm/min crosshead speed

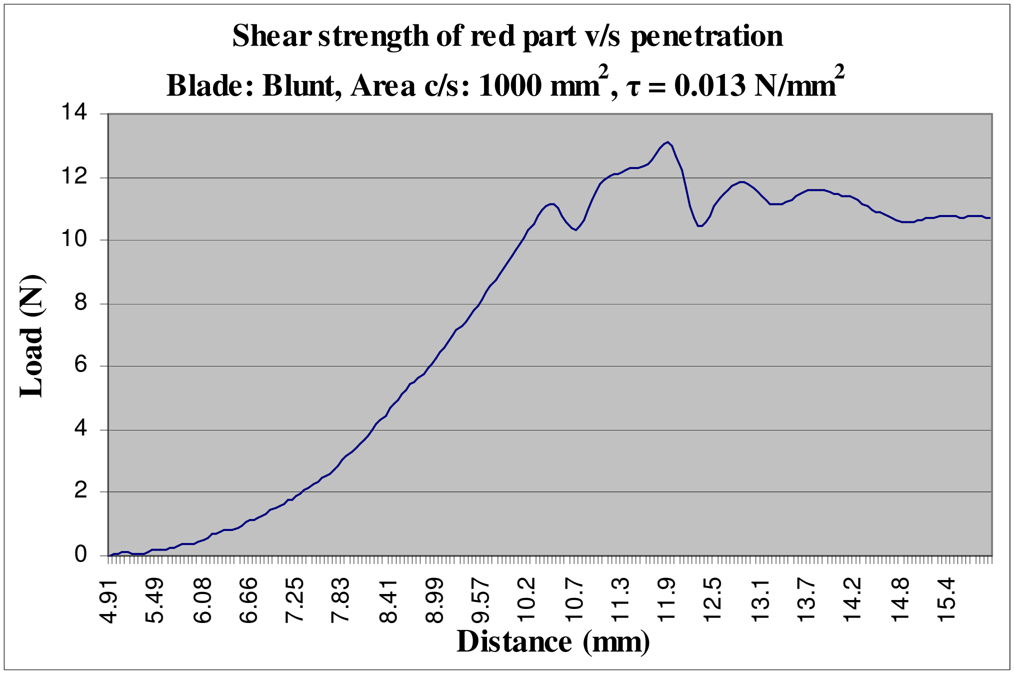

Figure C9: Shear strength of red part (region II of watermelon) @ 0.001 mm/min crosshead speed

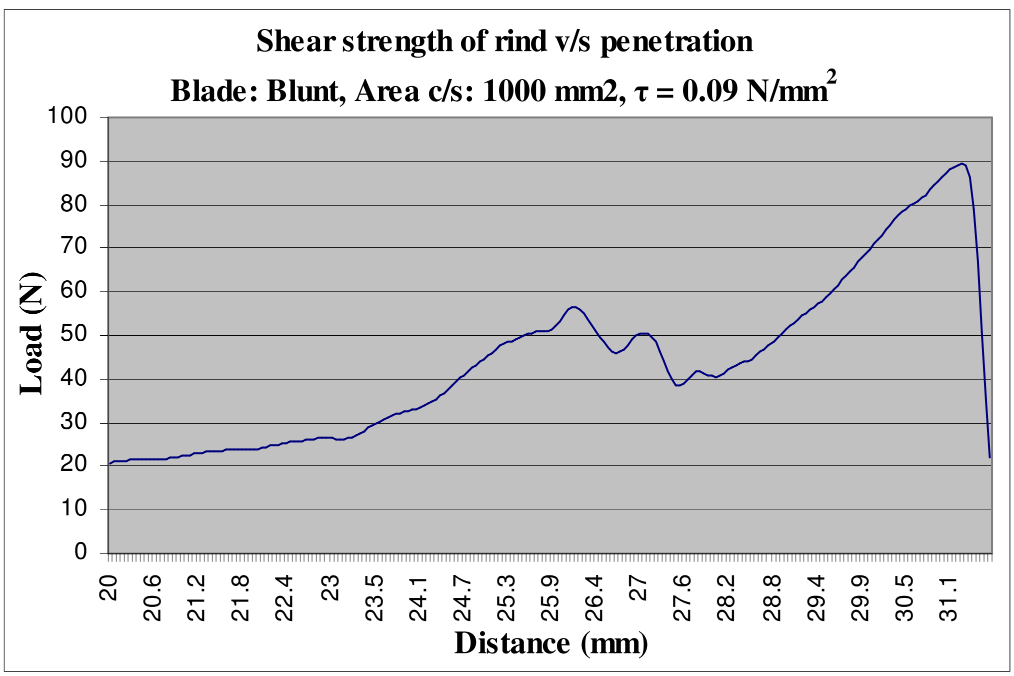

Figure C10: Shear strength of rind (region I of watermelon) @ 1270 mm/min crosshead speed

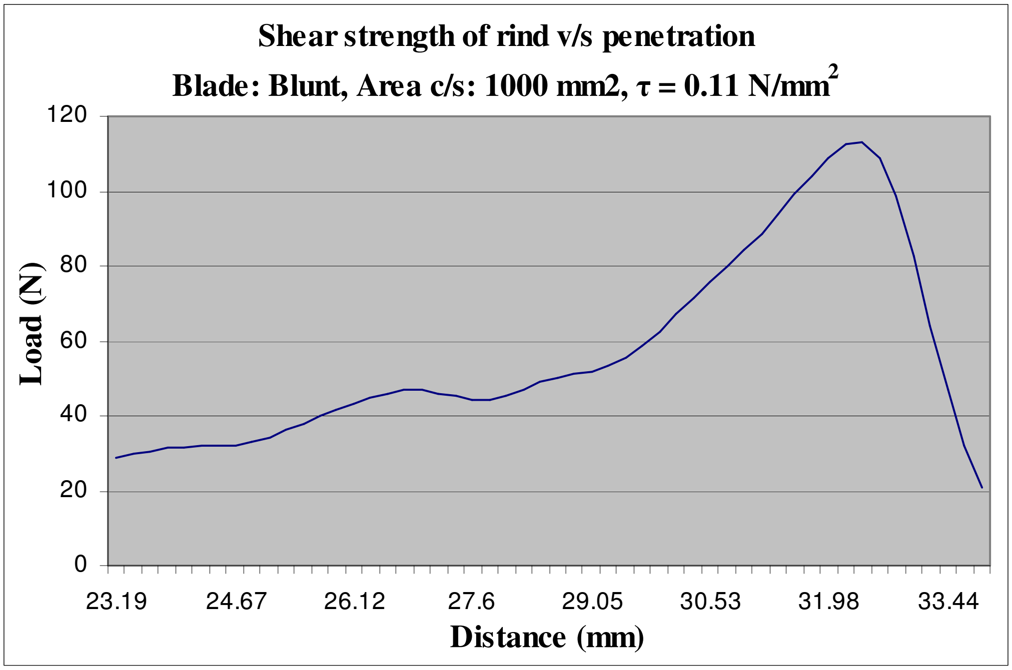

Figure C11: Shear strength of rind (region I of watermelon) @ 635 mm/min crosshead speed

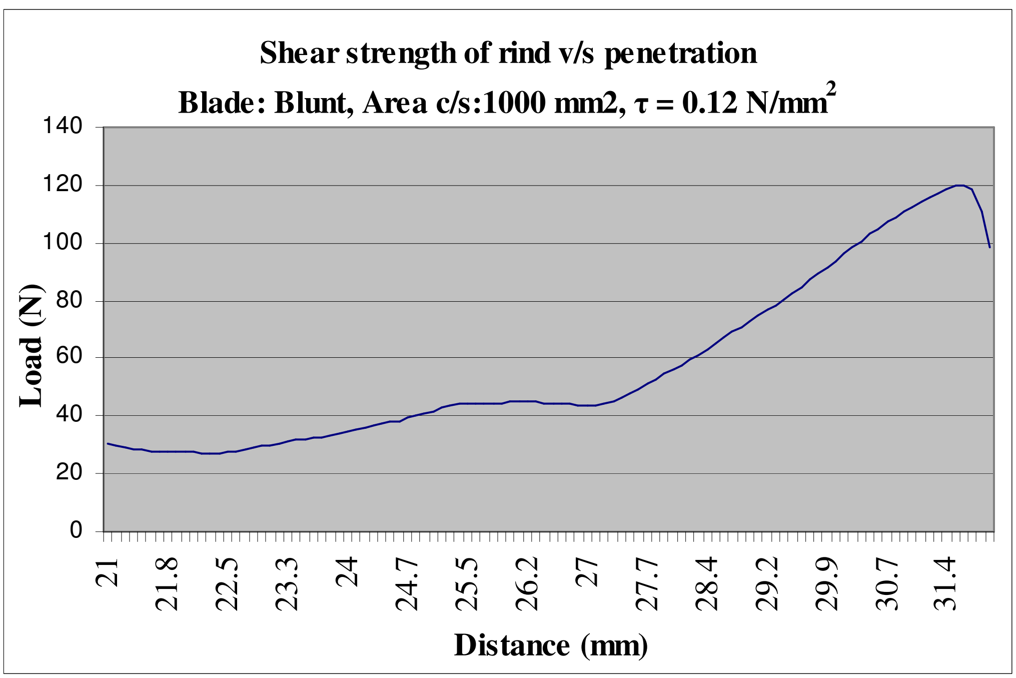

Figure C12: Shear strength of rind (region I of watermelon) @ 0.001 mm/min crosshead speed

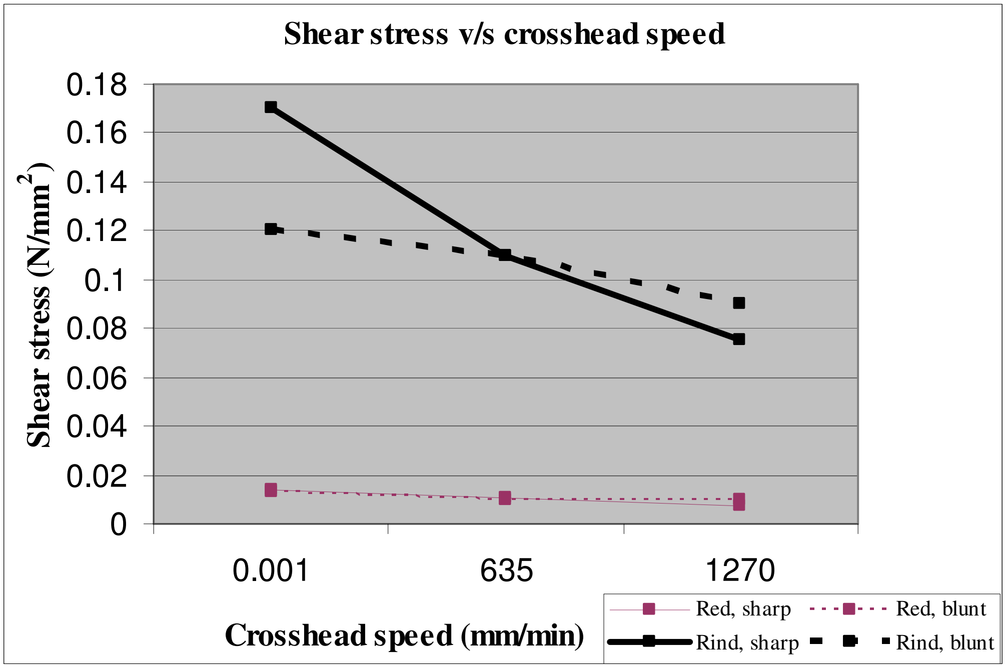

Figure C13: Relation of shear stress with crosshead speed

Note:

Red, sharp = Red part (region II of watermelon) cut by sharp edge blade.

Red, blunt = Red part (region II of watermelon) cut by blunt edge blade

Rind, sharp = Rind part (region I of watermelon) cut by sharp edge blade

Rind, blunt = Rind part (region I of watermelon) cut by sharp blunt blade

APPENDIX D – SPATIAL DISTRIBUTION OF SHEAR STRESS INSIDE A WATERMELON

A shear test was done to study the spatial distribution of shear stress inside the watermelon. A watermelon was divided into four sections (region I, II, III, and IV in figure D1) and one sample was taken from each section, of size 30 x 30 x 30 mm. The samples were hand cut from each section at room temperature. The watermelon used for this test was 200 mm in diameter. The blade used was a sharp-edge blade. The cutting speed was 1270 mm/min. The maximum shear stress in the sample from the four regions was measured by Instron shear testing machine.

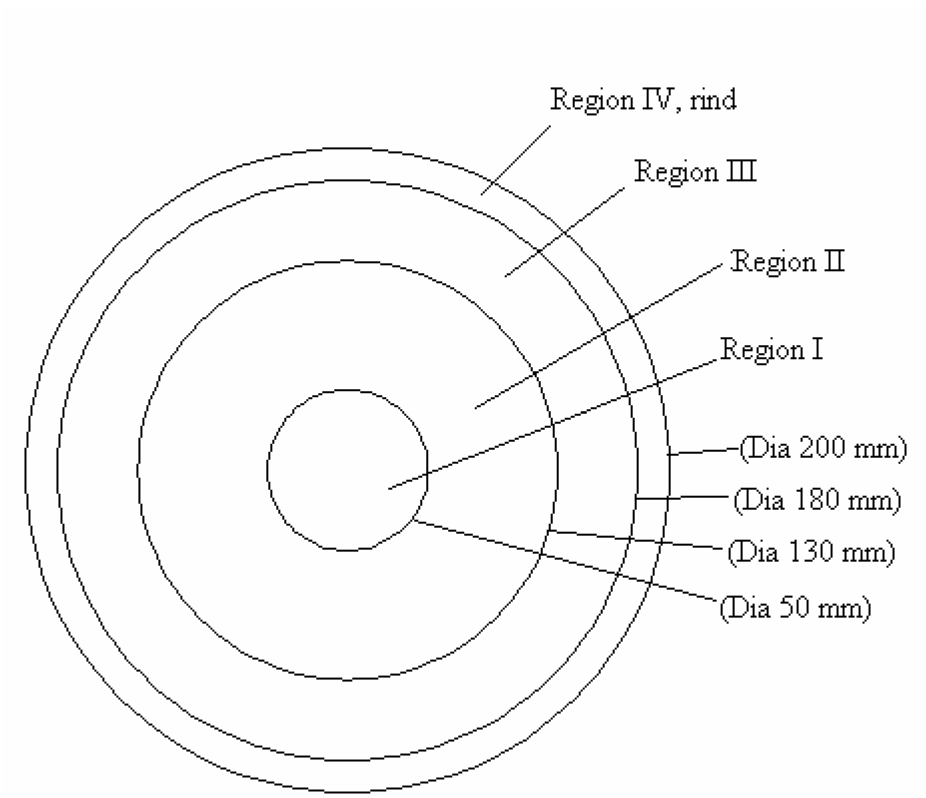

Figure D1: Schematic diagram showing different regions inside watermelon

Figure D2, D3, D4 and D5 shows the graph of shear stress recorded for region I, II, III and IV respectively. Figure D6 shows maximum shear stress recorded in region I, II, III and IV.

Table: D1. Maximum shear strength in different regions inside watermelon

Region	Maximum shear strength (N)	Maximum shear stress (N/mm^2)
I	4	0.005
II	5.5	0.007
III	10	0.014
IV	50	0.071

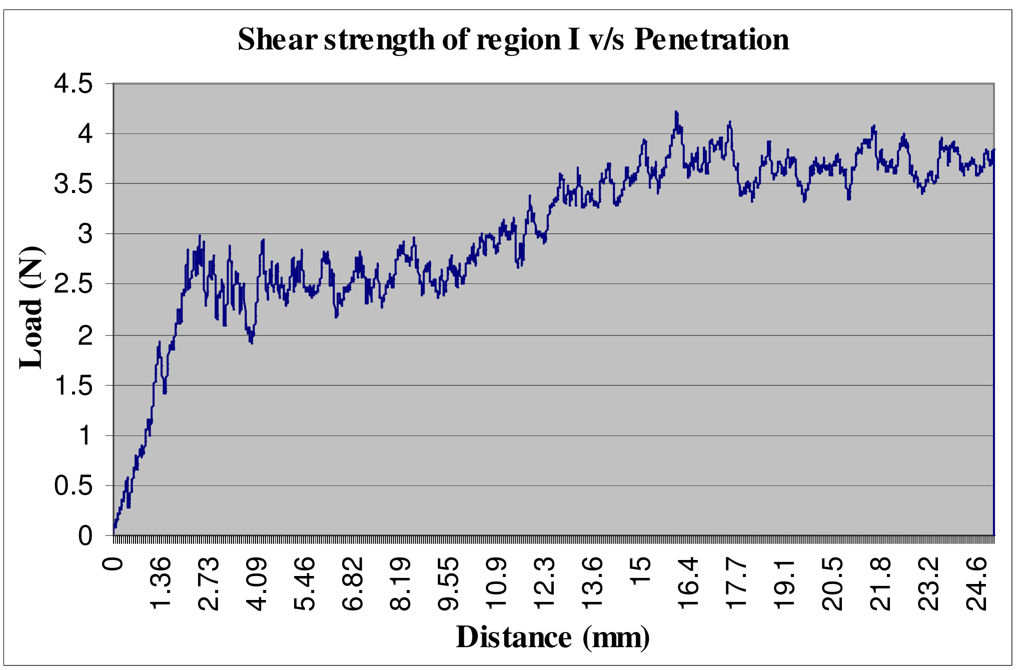

Figure D2: Shear strength of region I

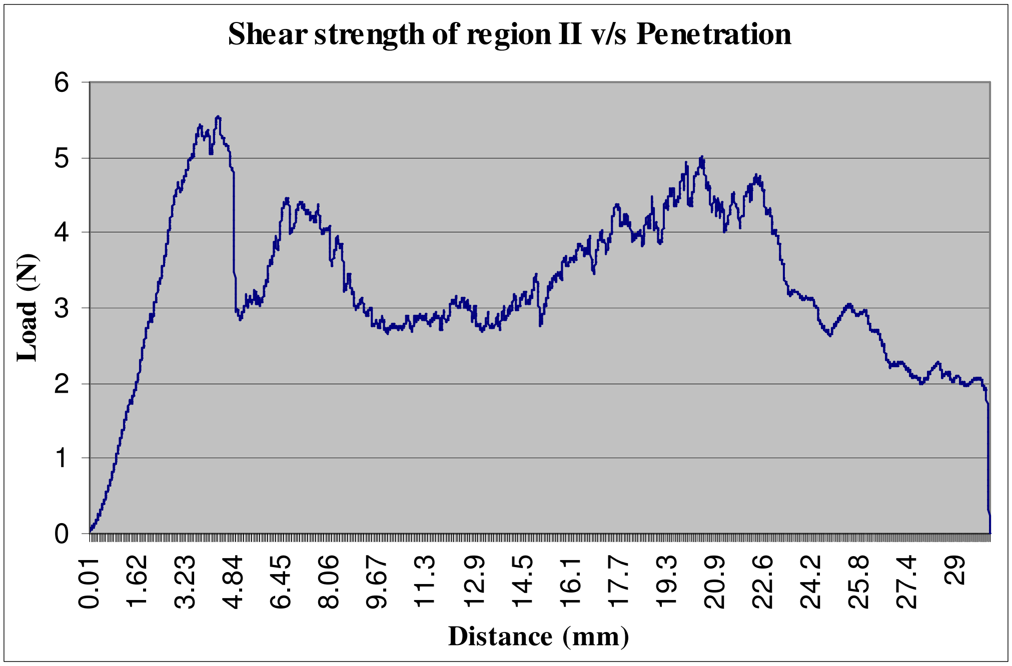

Figure D3: Shear strength of region II

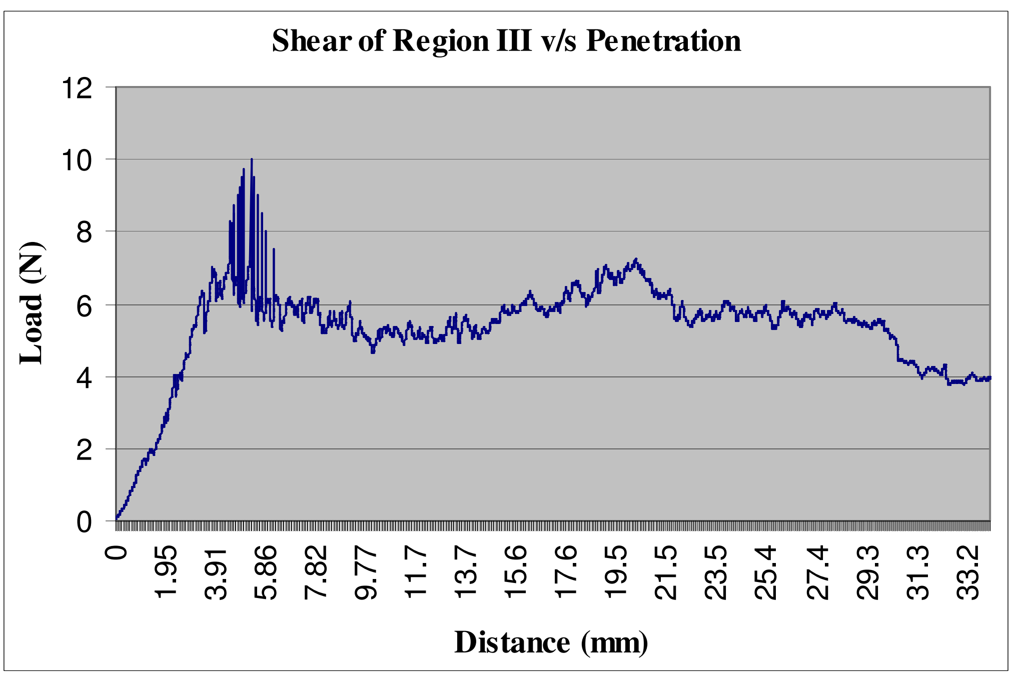

Figure D4: Shear strength of region III

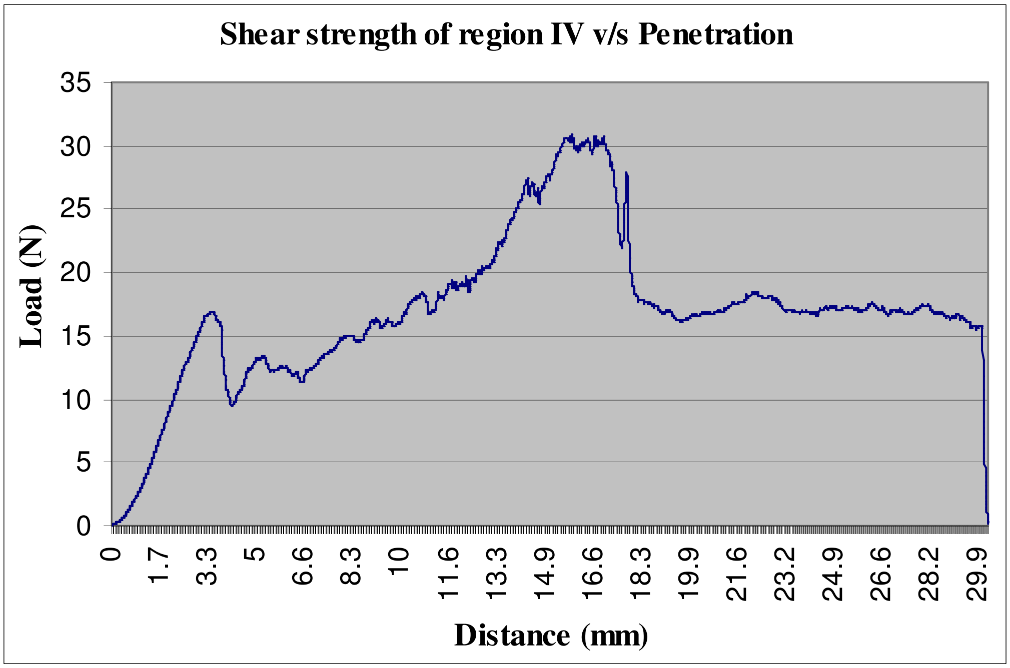

Figure D5: Shear strength of region IV

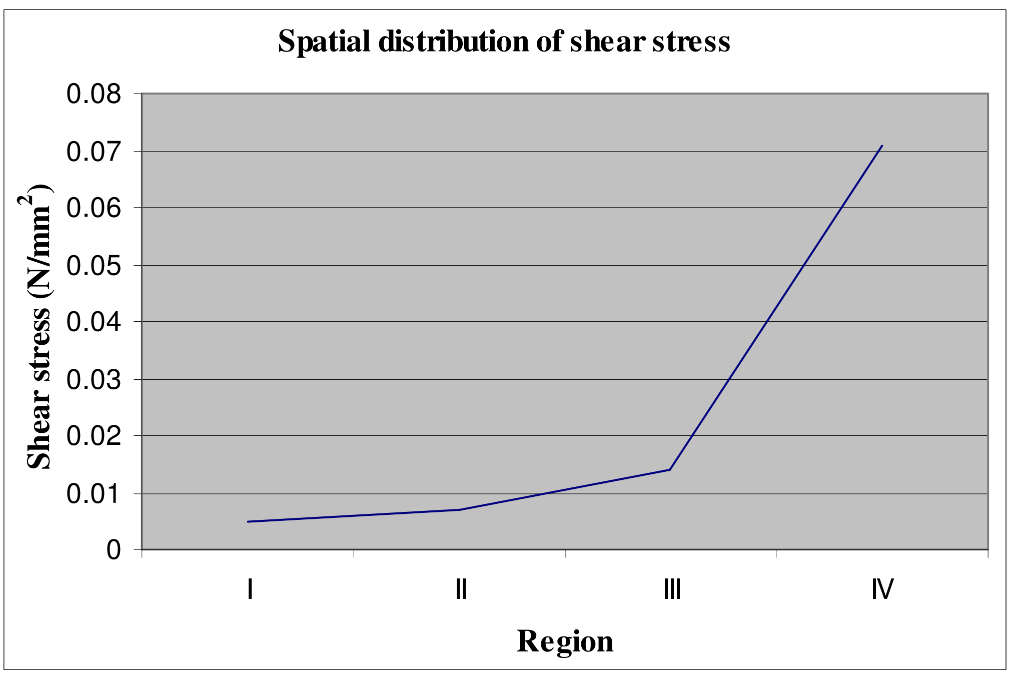

Figure D6: Spatial distribution of maximum shear stress

APPENDIX E – POWER REQURIED TO CUT ONLY THE RED WATERMELON FLESH

$P_1 = V_1 I_1 \qquad (E-1)$

$P_1 = Power\ drawn\ by\ motor\ to\ overcome\ its\ internal\ resistance\ and\ rotate\ blade\ (W)$

$V_1 = Voltage\ supplied\ (V) = 15.79$

$I_1 = Current\ drawn\ by\ motor\ to\ rotate\ blade\ (A) = 4.5$

$P_1 = 15.79 \times 4.5 = 71.055W$

$P_2 = V_2 I_2 \qquad (E-2)$

$P_2 = Power\ drawn\ by\ motor\ to\ overcome\ its\ internal\ resistance\ and\ rotate\ blade\ in$
$watermelon\ while\ cutting\ red\ flesh\ (W)$

$V_2 = Voltage\ supplied\ (V) = 15.79$

$I_2 = Current\ drawn\ by\ motor\ to\ rotate\ blade\ while\ cutting\ red\ flesh\ (A) = 5.2$

$P_2 = 15.79 \times 5.2 = 82.108W$

$P_3 = P_2 - P_1 \qquad (E-3)$

$P_3 = Power\ requried\ just\ to\ cut\ red\ flesh = 82.108 - 71.055 = 11.053W$

APPENDIX F – GRAPHICAL REPRESENTATION OF IMPACT FORCE BY ALUMINUM BLADE MEASURED EXPERIMENTALLY ON INSTRON MACHINE

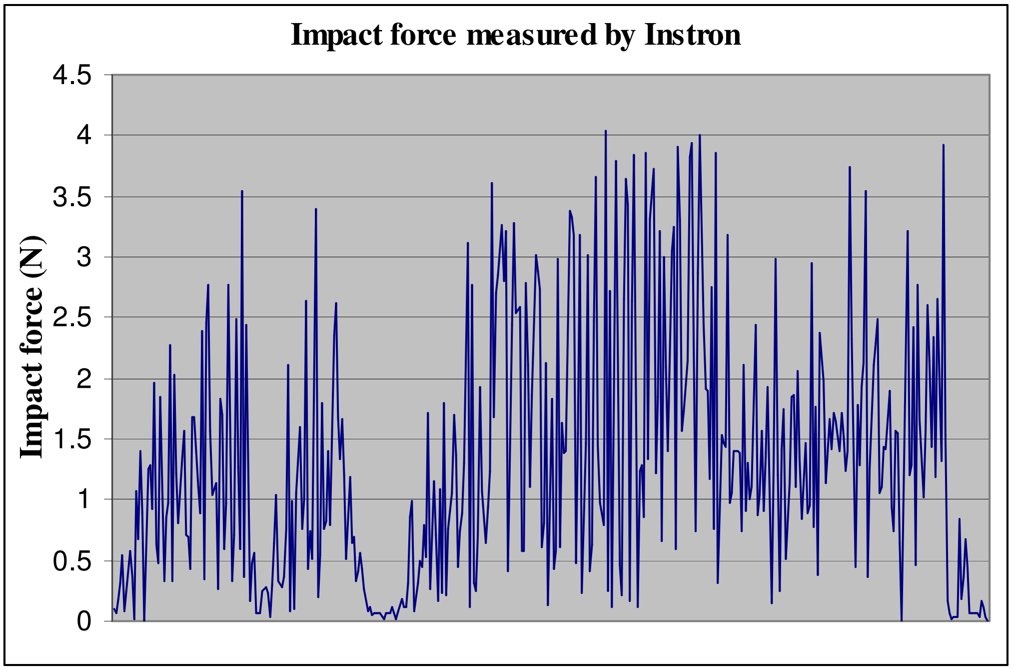

Figure F1: Impact force by aluminum blade measured by Instron machine

As shown in figure F1, the impact force of the 3-blade measured by the Instron machine ranged from approximately 1 to 4 N at 1200 rpm.

APPENDIX G – TOTAL NUMBER OF IMPACTS PER REVOLUTION

G.1 Method 1:

$$Impact\ Force(N) = Impact\ Impulse(kg\text{-}m/sec)/dwell\ time(sec)$$

$$= (M/t)\left\{(1+c)\times\left[(\frac{2}{M})\times(W)\right]^{1/2} - (\frac{r}{d})\times(cS_1+S_2)\right\} \qquad (G\text{-}1)$$

where,

$Impact\ force = 4\ N\ (from\ experimental\ method)$

$M = Mass\ of\ blade\ (kg)$

$t = Dwell\ time\ i.e.\ time\ required\ to\ reduce\ from\ initial\ velocity\ to\ zero\ velocity$

$c = Coefficient\ of\ restitution$

$W = Work\ done\ in\ impact\ (N\text{-}m)$

$r = Distance\ between\ center\ of\ mass\ and\ axis\ of\ rotation\ (m) = 0.045\ m$

$d = Distance\ between\ impact\ point\ and\ axis\ of\ rotation\ (m) = 0.045\ m$

$S_1 = Linear\ velocity\ of\ blade\ before\ impact\ (m/sec)$

$S_2 = Linear\ velocity\ of\ blade\ after\ impact = 0\ m/sec$

$V_1 = Linear\ velocity\ of\ watermelon\ before\ impact = 0\ m/sec$

$V_2 = Linear\ velocity\ of\ watermelon\ after\ impact = 0\ m/sec$

$N = Speed\ of\ blade = 1200\ rpm$

$$w = Angular\ velocity\ of\ blade = \frac{2\times 3.14\times 1200}{60} = 125.6\ rad/sec$$

$$S_1 = r\times w = 0.045\times 125.6 = 5.652\ m/sec$$

$$c = \frac{S_2 - V_2}{V_1 - S_1} = \frac{0-0}{0-5.652} = 0$$

$$W = \frac{1}{2}\times M\times S_1^{\,2} = 0.5\times 0.004\times 5.652^2 = 0.0638\ N\text{-}m$$

$$4 = (\frac{0.004}{t})\left\{(1+0)\times\left[(\frac{2}{0.004})\times(0.0638)\right]^{1/2} - (\frac{0.045}{0.045})\times(0\times 5.652+0)\right\}$$

$t = 0.005\ seconds$

$let, Y = total\ number\ of\ impacts$

$(assume\ each\ impact\ duration\ is\ same\ and\ no\ time\ is\ lost\ between\ each\ impact)$

$Time\ taken\ to\ complete\ one\ revolution = 0.05\ seconds$

$$Y = \frac{\frac{1}{(1200/60)}}{0.005} = 10$$

G.2 Method 2:

$$T = I\alpha$$

$$I = mk^2$$

$$\alpha = \frac{(\omega_2 - \omega_1)}{\Delta t} \qquad (G-2)$$

$$\omega_1 = \frac{2\pi N_1}{60}$$

$$\omega_2 = \frac{2\pi N_2}{60}$$

$Where,$

$T = Torque\ (N-m)$

$I = Moment\ of\ Inertia\ (kg-m^2)$

$\alpha = Angular\ Acceleration\ (rad/sec^2)$

$m = Mass\ of\ blade\ (kg) = 0.004\ kg$

$k = Length\ between\ axis\ of\ rotation\ and\ mass\ (m) = 0.045\ m$

$(In\ this\ research\ it\ is\ assumed\ total\ mass\ of\ blade\ is\ concentrated\ at\ the\ midpoint\ of\ the\ length\ of\ blade)$

$N_1 = Initial\ speed\ of\ blade\ (rpm) = 1200\ rpm$

$(Initial\ speed\ is\ speed\ of\ blade\ before\ impact)$

$N_2 = Final\ speed\ of\ blade\ (rpm) = 0\ rpm$

$(Final\ speed\ is\ speed\ of\ blade\ at\ end\ of\ impact, it\ is\ assumed\ that\ blade\ comes\ to\ rest\ at\ the\ end\ of\ impact)$

$\omega_1 = Initial\ angular\ velocity\ (rad/seconds) = 125.663\ rad/sec$

$\omega_2 = Final\ angular\ velocity\ (rad/seconds) = 0\ rad/sec$

$Therefore,$

$\Delta t = Time\ between\ start\ of\ impact\ and\ end\ of\ impact\ (seconds)$

$$I = 0.004 \times (0.045)^2 = 8.1 \times 10^{-6}$$

$$a = \frac{(0 - 125.663)}{\Delta t}$$

In rotational motion torque is force required to rotate a body about an axis therefore,

$$T = Fr$$

Where,

$F = Force(N) = 4\,N$ *(taken from experimental method)*

$r = $ *Distance of force from axis of rotation* $(m) = 0.045\,m$

$$T = 4 \times 0.045 = 0.18\,N\text{-}m$$

$$a = \frac{T}{I} = \frac{0.18}{8.1 \times 10^{-6}} = 22222\ rad/sec^2$$

$$t = \frac{125.663}{a} = \frac{125.663}{22222} = 0.005\ seconds$$

let, $Y =$ *total number of impacts*

(assume each impact duration is same and no time is lost between each impact)

Time taken to complete one revolution $= 0.05$ *seconds*

$$Y = \frac{\frac{1}{(1200/60)}}{0.005} = 10$$

Thus it could be seen that from both methods the total number of impacts per revolution is 10.

APPENDIX H – TEST CONDUCTED WITH PLASTIC STRING AS BLADE

Tests were conducted using a flexible string made of plastic (as the cutting blade) instead of aluminum. This experiment was conducted to investigate the role of plastic instead of metal blade, because plastic could reduce the weight of the equipment and the manufacturing cost. In this test, only two parameters were measured, first the satisfactory cutting speed, and second the impact force of string on red watermelon flesh. The procedure for measuring cutting speed and impact force was same as that described for 3-blade assembly in section 3.3.5 and 3.3.7 respectively. In addition to the above two test cutting sequence of plastic string inside the watermelon was observed.

Figure H1 shows a plastic string (Xtreme, Arnold Corporation, OH) fixed to one end of aluminum shaft.

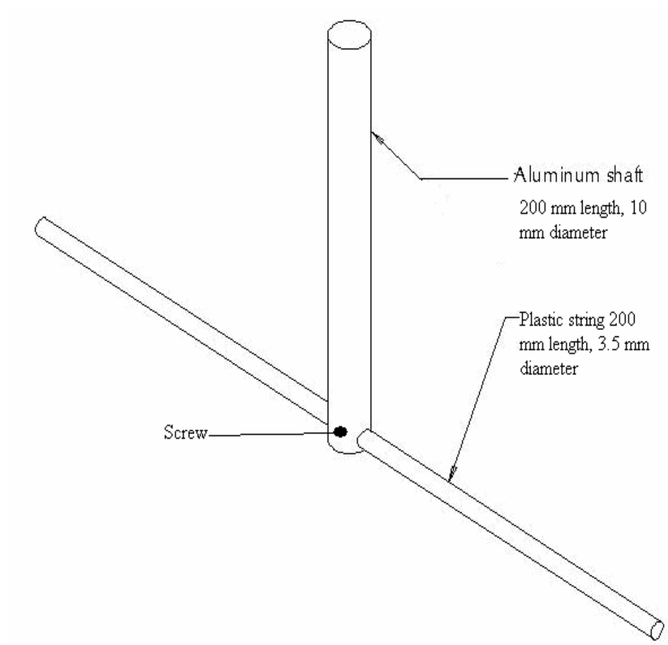

Figure H1: Schematic diagram of plastic string as blade

The string used for this experiment is commonly used in weed eater machines. Its diameter was 3.5 mm and length 200 mm. The shaft was 10 mm in diameter and 200 mm in length. The plastic string was fixed to the shaft by using a screw. The other end of the shaft was connected to chuck of the drill motor.

To study the cutting sequence of plastic string inside a watermelon a half-cut watermelon was used. The string was rotated inside the watermelon.

OBSERVATION

1. The satisfactory cutting rate was observed at 2500 rpm
2. If the available string force was greater than the force required to shear rind, the string would cut a hole in rind and juice would flow out from the hole.

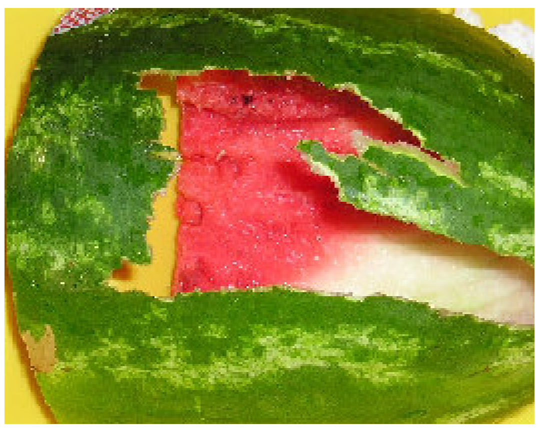

Figure H2: Photograph of a hole cut in the rind of watermelon at 3500 rpm

3. As the string cross-section size increases, the rate of juice formation also increases, but increased cross-section reduces flexibility of the string and hence sets permanent deformation in string.

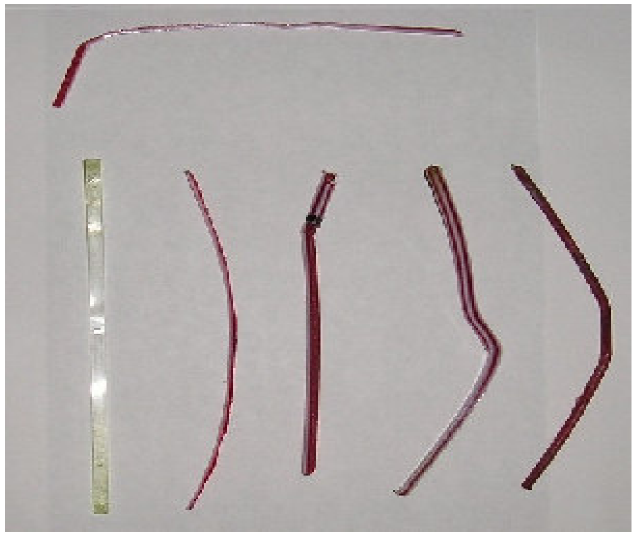

Figure H3: Photograph of deformed strings

4. The maximum impact force generated by the string was measured as 3.5 N by the Instron machine. Please refer figure H4 for the graph recorded using Instron machine.

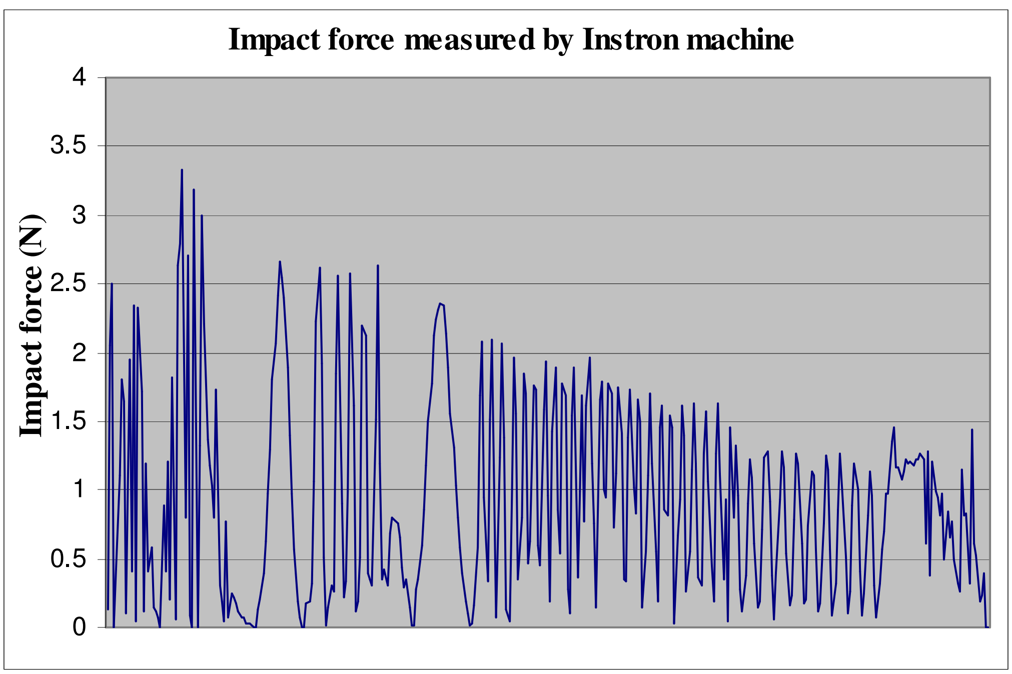

Figure H4: Impact force by plastic blade measured using Instron machine

5. The visual observation of cutting sequence of plastic string showed that the string took a V-shape at the entry of the bore (shown in position 1 of figure H5). While revolving the string began to hit the red watermelon flesh. With each impact the string penetrated the red watermelon flesh and was dislodged at the end of the impact. If the shaft was shifted to one side, as in position 3, the string could bend and prevent any cutting of the red watermelon flesh. The amount of bend in the string at its end depended on the shear strength of the red watermelon flesh or rind. If the obstruction was very tough the bend could be greater, if the obstruction was very soft there might be no bend in the string. The amount of bend in the string could depend on the mechanical properties of the string. If the string was very tough to bend then the amount of bend in the string could be much less. Thus the combination of mechanical properties of string, shear strength of the watermelon and the rotational speed were important parameters to determine feasibility of plastic instead of metal.

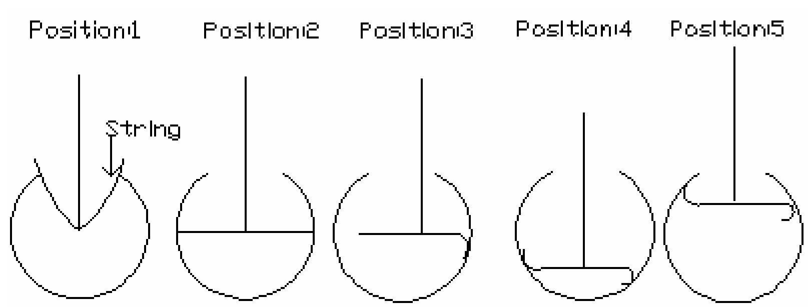

Figure H5: String at different positions inside watermelon while cutting.

The young's modulus of the plastic string was an important parameter in design of plastic string as blade. To calculate young's modulus the plastic string could be assumed to be cantilever beam supported at one end on the aluminum shaft.

The young's modulus of cantilever supported beam could be calculated by the following formulae.

$$E = \frac{(0.224W) \times (2L - 3L^2 a + a^3)}{6yI}$$

Where,

$E =$ *Young's Modulus of the plastic string (lb/mm²)*

$W =$ *Load applied at the tip of the plastic string (N)*

$a =$ *Distance between the load and shaft axis (mm)*

$L =$ *Length of the string (mm)*

$y =$ *Deflection requried at the tip of the plastic string (mm)*

$I =$ *Section modulus (mm⁴)*

VITA

Harish J. Bangera

Candidate for the degree of

Master of Science

Thesis: INVESTIGATION OF A WATERMELON PULP FRUIT AND JUICE EXTRACTION DEVICE

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Experience: Worked with D. Parikh Engineering works, Mumbai, India as Intern-Design Engineer, 1996; worked with SYP Engineering Corporation, Mumbai, India as service Engineer, 1998; Employed by Cadmach Machinery Company Private Limited, Mumbai, India as Sales and Service Engineer, 1998-2001; worked for Ingersoll-Rand (I) Limited as Application Engineer, 2002. Worked as Graduate Research Associate at Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK, 2003 –2004.

Name: Harish J. Bangera Date of Degree: May, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INVESTIGATION OF A WATERMELON PULP FRUIT AND JUICE EXTRACTION DEVICE

Pages of study: 82 Candidate for the Degree of Master of Science

Major Field: Biosystems and Agricultural Engineering

Abstract:

This research was a part of a larger effort to extract lycopene from watermelons focusing on *in situ* juice extraction from watermelons. The conventional method of juice extraction needs watermelons to be transported to processing factory. Transporting watermelons from farm to processing factory involves, labor, time and cost. To reduce cost by all these factors, it was understood a better method would be a handheld machine, light in weight and easy to carry in the watermelon field. The rind left on the field can be used as cattle food or manure for the same field; this would be an efficient way to replenish the minerals consumed from the soil for growing watermelons.

Methods, Findings and Conclusions:

A prototype machine was developed; this machine bore a hole in the rind of watermelon and then a set of three blades enters the watermelon fruit. A handheld battery operated motor rotated these blades. The impact force of each blade sheared the red watermelon flesh into juice.

Adviser's approval____