EML 4551 Senior Design Project Organization

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

In Situ Analysis between Reinforced Fibers
25% Senior Design Report

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November 7, 2012

This B.S. thesis is written in partial fulfillment of the requirements in EML 4551.
The contents represent the opinion of the authors and not the Department of
Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of JEAN PAUL ARROYO and EDUARDO ESCOBAR and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Table of Contents

List of Figures

List of Tables

Abstract

The American Society for Testing and Materials (ASTM) currently has a defined standard for measuring the coefficient of friction between yarns. However, this standard is not recommended due to a lack of precision among different laboratory testing. This variance can likely be attributed to slight differences in environment as well as natural human error.

Brisk Engineering has decided to take on the task of re-creating this testing standard, and modifying it in such a manner that the previously-mentioned “lack of precision” would be a problem of the past. The proposed design will take the current testing standard, and miniaturize it to the point of being fit for analysis under a scanning electron microscope (SEM). Other features planned for the design are the additions of remotely-adjustable input tensions and yarn collection speeds.

The team will be working in collaboration with Dr. Benjamin Boesl, who specializes in the implementation of the novel experimental testing procedures as well as the computational methods. This project has the potential to have a much broader impact than simply rubbing strings together. By updating the testing standard, other researchers will be able to conduct similar experiments and achieve precise and comparable results. This project should serve a useful purpose to anybody in the field of Material Sciences.

1.1 Problem Statement

The design of an updated model of the ASTM standard is required in order to maintain precision among laboratory tests, and thereby deserve the recommendation by ASTM for practical and accurate use. The goal is to standardize this model by creating one small universal testing apparatus, as well as incorporating SEM imaging for further precision.

Because of the intent to use a scanning electron microscope, the testing apparatus must be SEM-compatible. This means that, ideally, all materials used in the device must be electrically conductive. In addition, all moving parts accountable for the movement of components (the motor and actuator) must be vacuum compatible. Aside from challenges in selecting proper materials, another task is to select components that, when assembled, will still be smaller than the allotted testing chamber of the SEM. This means that the entire testing device must have dimensions of approximately 170mm x 120 mm x 50 mm.

Finally, since the device will be inside a vacuum chamber, it is essential to have digital measurement readings that are accessible from the outside of the SEM for the input and output tensions, as well as for the speed at which the yarns will be moving. In addition to being accessible, the input tension and rotation speed should also be remotely adjustable in order to maximize testing time.

1.2 Motivation

The motivation behind this project is to create a globally-accepted standard that measures the friction coefficient between yarns in a precise and controlled manner. It is rather evident that there is room for improvement when the ASTM announces on its own website that the current testing standard that it suggests is not recommended.

The use of this device goes beyond the scope of simply calculating friction coefficients. Understanding the manner in which the hundreds of different kinds of these fibers react to one another may open the door to the development, testing, and analysis of reinforced and enhanced fibers with much better and stronger material properties.

Once the design for the device is complete and a prototype is manufactured, further research can be done to understand the impact of surface coating on fiber friction. The project's research can benefit many different applications; with the potential in improvements from military apparel to commercial clothing and athletic gear. There is an intellectual merit of this proposed project, providing a possible pathway to publishing any findings generated from conducting experiments using the apparatus. It will require knowledge and research in the dynamic progressive failure analysis of 3D woven composite systems.

1.3 Literature Survey

In Situ Friction Analysis

We will be working on the twisted strand method for this design. "Based on the measurement results, effects of yarn axial tension, angle between yarns, yarn sliding speed and temperature on the yarn-to-yarn friction are investigated and discussed. "[1] We will be measuring the mean input tension (T_1), mean output tension (T_2), the apex angle (α), and zero twist tension (Δ*T).* The number of wraps in the twisted strand method, input and output tensions, and apex angle are known before the test is conducted. This information will allow us to find the coefficient of friction (μ) by the use of the equation in **Figure 1**. By this we can understand the behavior of these fibers and this test can be used to predict the shear response and failure mechanisms in analytical and numerical models. To understand the science and theory behind our design we first had to go over some terminologies and definitions. The following definitions come from the journal STANDARD TEST METHOD FOR COEFFICIENT OF FRICTION, YARN TO YARN, written by ASTM INTERNATIONAL.

- *Boundary friction, n—friction at low sliding speeds (0.02 m/min or less) where lubrication occurs under thin-film lubricant condition.*

- *Coefficient of friction, n—the ratio of the tangential force that is needed to maintain uniform relative motion between two contacting surfaces to the perpendicular force holding them in contact.*
- *Friction, n—the resistance to the relative motion of one body sliding, rolling, or flowing over another body with which it is in contact.*

- *Radian, n—the plane angle between two radii of a circle which intersects the circumference of the circle making an arc equal in length to the radius.*

- *Stick-slip, n—a phenomenon occurring when boundary lubrication is deficient, manifested by alternative periods of sticking and slipping of the surfaces in contact.*

- *Discussion—At the specified sliding speed, in yarn friction testing, stick-slip cycles are long enough that they can be readily recorded. During sticking, the frictional force slowly rises to a peak value, at which the slipping occurs with the frictional force rapidly decreasing to a minimum value.*

- *Wrap angle, n—in yarn friction testing, the cumulative angular contact of the test specimen against the friction inducing device, expressed in radians.*

$$\mu = \frac{\ln \dfrac{T_2 - \Delta T / 2}{T_1 + \Delta T / 2}}{2\pi n \alpha}$$

Figure 1: Equation used to calculate friction coefficient

It is recommended [1], while using the twisted strand method, to use a wrap angle of 15.71 radians. This test varies from lab to lab. So this test is not recommended for commercial uses at this time. We hope to change this with our apparatus by use of SEM integration. When labs decided to use this test for commercial uses, the buyer and supplier of the product tested, would both have labs that would test their product. They would try to make their specimen homogeneous. There would be an average taken of the results. If there would be a bias from either lab they would find out what that bias was and make adjustments.

Apparatus

The following description of the twisted method apparatus has been taken from the journal STANDARD TEST METHOD FOR COEFFICIENT OF FRICTION, YARN TO YARN, written by ASTM INTERNATIONAL.

(Twisted Strand Method)—A schematic diagram of the elements required for twisted strand friction measurement is shown in Fig. 1. The yarn is run over upper pulleys and under a lower pulley and is intertwisted between these pulleys. One end of the yarn (output) is taken up at a controlled rate. The other end of yarn (input) is maintained at a controlled tension. The number of intertwisting wraps, the apex angle between the input and output yarns, and the input and output tensions are precisely known or recorded. From these data the coefficient of yarn-on-yarn friction is calculated.

The required elements are:

- *Friction Testing Apparatus (Indirect)3—Apparatus in which the input tension is measured, or controlled to a set value, the output tension is measured, and the coefficient of friction is calculated within or outside the apparatus.*

- *Yarn Input Tension Control—Ameans of controlling the yarn input tension to the nearest 5 % is required. A demand-feed apparatus tensioned with a fixed weight is suitable.*

- *Yarn Input Tension Measurement—The yarn input tension is measured to within 65.0 mN (60.5 gf), using a suitable tension gage producing an electrical signal. The signal is recorded as millinewtons (grams-force) or is used in combination with the yarn output tension measured to calculate the coefficient of friction. If a demand-feed apparatus tensioned with a precise, known fixed mass is used, the yarn input tension need not be constantly measured and recorded.*

- *Yarn Output Tension Measurement—Yarn output tension is measured to within 65.0 mN (60.5 gf), using a suitable tension gage producing an electrical signal. The signal is recorded as millinewtons, (grams-force), or is used in combination with the yarn input tension setting or measurement to calculate the coefficient of friction.*

- *Friction Testing Apparatus (Direct)4—Apparatus in which the ratio of output to input tensions are compared directly and the coefficient of friction is indicated on a scale.*

- *Auxilliary Equipment (Indirect and Direct):*
  Guide Pulley Arrangement—The upper and lower pulleys shalls be of the same diameter. The recommended pulley diameter is 38 mm (1.5 in.). The separation distance between the upper pulleys, 2 H, shall be 140 6 2 mm (5.5 6 0.1 in.). The separation distance between the axis of the lower pulley and a line connecting the upper pulley axes, V, shall be 280 6 2 mm (11 6

0.1 in.). All pulleys shall be in the same plane. The lower pulley may optionally be mounted so that it can be swiveled around an axis at right angles to its axis of rotation and then fixed in position in the same plane as the upper pulleys.

- *Drive Unit—The yarn takeup shall run between 2 and 100 mm/min (0.75 and 4.0 in./min).*

Material & Component Selection

Because it is in a SEM all materials should be conductive. We propose that our design to be made from aluminum. This includes the pulleys, the testing platform, actuator and tension gauges. The proposed design that will be covered later will have aluminum plates welded together or screwed together to create the testing platform. This platform must be sturdy enough to handle the vacuum environment of the SEM. The vacuum pressure will be 10^{-5} millibar. The drive unit will be a servomechanism motor, with variable speed, whose height must be smaller than 50mm. This motor will be attached to a pulley which will take up the yarn between 2 and 100 mm/min. There will also be an actuating system to that is needed to increase the tension of the yarn or fiber. This too will be implemented by use of a servomechanism motor attached to an arm that will pull down on the yarn to increase the tension.

Material Properties						
Material	Aluminum		Titainum		Steel 4000 series	
Units	English	Metric	English	Metric	English	Metric
Density	2.6989 g/cc	0.097504 lb/in^3	4.50 g/cc	0.163 lb/in^3	7.80 g/cc	0.282 lb/in^3
Modulus of Elasticity	68.0 Gpa	9860 ksi	116 Gpa	16800 ksi	205 Gpa	29650 ksi
Shear Modulus	25 Gpa	3630 ksi	43.0 Gpa	6240 ksi	78.5 Gpa	11400 ksi
Hardness, Vickens	15	15	60	60	36.0 - 614	36.0 - 614
Heat Fusion	386.9 J/g	166.4 BTU/lb	435.4 J/g	187.3 BTU/lb	no information	no informaition
CTE,linear	24 µm/m˚C	13.3 µin/in˚F	8.90 µm/m˚C	4.94 µin/in˚F	10.4 - 14.6 µm/m˚C	5.78 - 8.11 µin/in˚F
Specific Heat	0.900 J/g˚C	0.215 BTU/lb˚F	0.528 J/g˚C	0.126 BTU/lb˚F	0.473- 0.477 J/g˚C	0.112 BTU/lb˚F
Melting Point	660.37˚C	1220.7˚F	1660˚C	3020˚F	1370 ˚C	2500 ˚F

Table 1: Material Properties

Figure 2: Servomechanism motor with variable speed for pulley

Figure 3: Servomechanism motor with variable speed for actuator

Figure 4: Impact ICP® quartz force sensor

1.4 Conceptual Designs

The concepts thought of during the early phases of design all coincided with the ASTM's current standard, testing method D3412, which is pictured below. As shown by **Figure 2**, the test consists of a singular long thread of yarn passing through multiple pulleys, eventually interacting with itself in a helix before being recovered by another rotating spool. There are also gauges used to measure the tension in the yarn before and after the helix interaction. Finally, preceding the input tension gauge is some sort of adjustable input tension device.

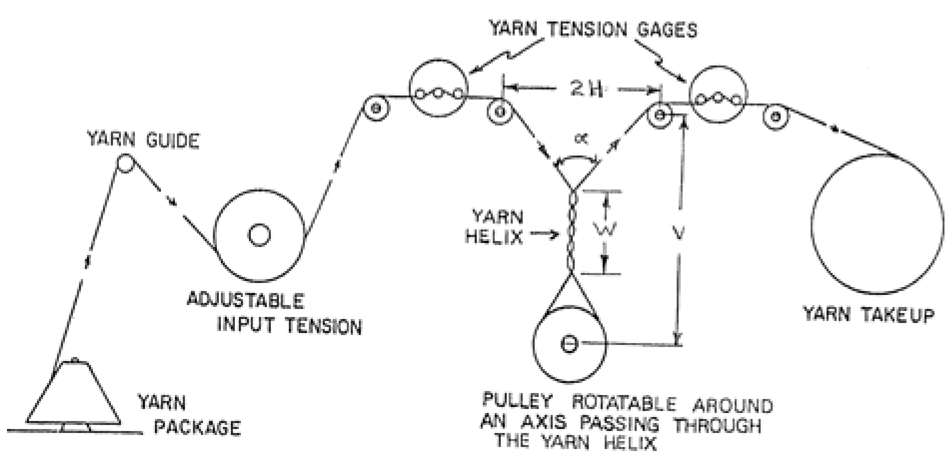

Figure 5: ASTM Testing Method D3412

While this testing method is an excellent starting point towards creating a final design, several modifications would be required in order to create an ideal testing device. Most of the current available testing devices are far too large for the intended purpose of this project. As shown in **Figure 3** below, the LH-402 Dynamic Tensile Tester is just one of the many existing machines capable of conducting the D3412 testing method. It has all of the necessary components to run an effective test. However, with dimensions of 119cm x 152cm x 160cm, this device is at least 10 times larger in each dimension than anything that can fit within the testing chamber of an SEM.

Figure 6: LH-402 Dynamic Tensile Tester

Another similar design exchanges the input tension device for an adjustable hanging weight, as shown in **Figure 4**. By changing the amount of weight at the beginning of the yarn, the tension going into the helix can be calculated, and the friction coefficient can then be calculated as usual. While a simpler design in theory, the problem lies not only in the inability to quickly and remotely change the weight, but also in the fact that a device of this type would require much more space in order to conduct a good amount of experimentation. Therefore, this design is impractical for this project's intentions.

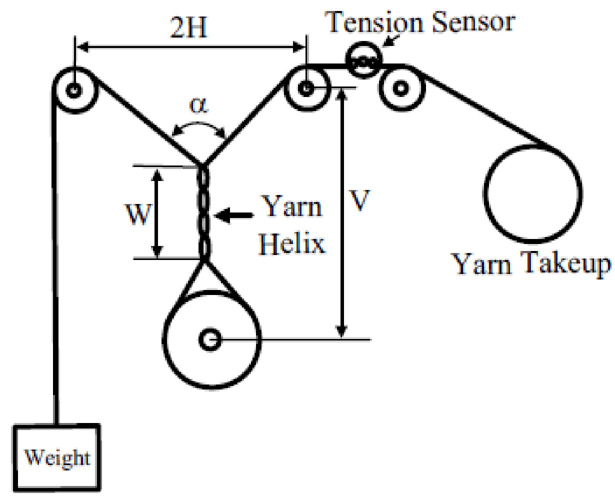

Figure 7: Weighted Conceptual Design

1.5 Proposed Design

After taking into consideration the advantages and disadvantages of previous designs, as well as the required components in the testing device, a compromise was finally achieved between size and function. The final product, shown in **Figure 5** below, utilizes the maximum amount of space allotted (170mm x 120mm x 50mm) in order to include all of the necessary components.

The goal of this design is to utilize all available space effectively, making the measuring components as small as possible while maximizing the size of the spools. By having larger spools, more yarn can be stored, and therefore more testing can take place. In addition, by making the two spools of the same size, it allows for interchangeability once a full spool of testing has taken place.

The proposed design was made using Solid Works. The model consists of three pulleys, a small servomotor to spin the spool collecting the yarn at a rate of .75 – 4 inches per minute), two tension gauges (before and after the helix interaction), and an actuator (to adjust the tension going into the helix). The yarn will be wrapped in a helix around the center pulley, where the fiber will rub against itself through multiple points in the helix. The ability to view multiple interactions under an SEM, as opposed to only seeing the change in tension through one point, will give researchers a much greater understanding of the interactions that take place among these yarns interacting with each other.

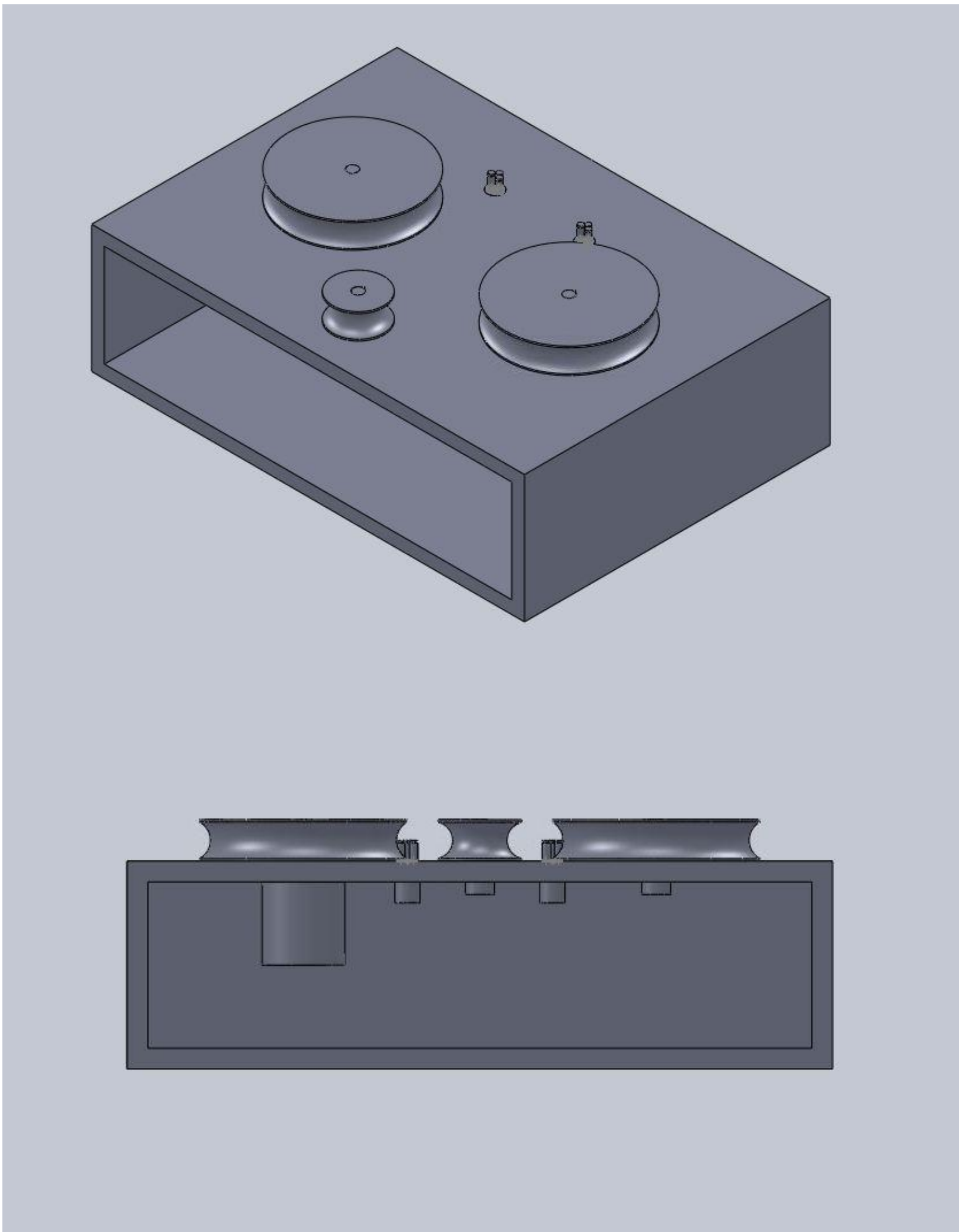

Figure 8: Proposed Design

1.6 Timeline and Project Organization

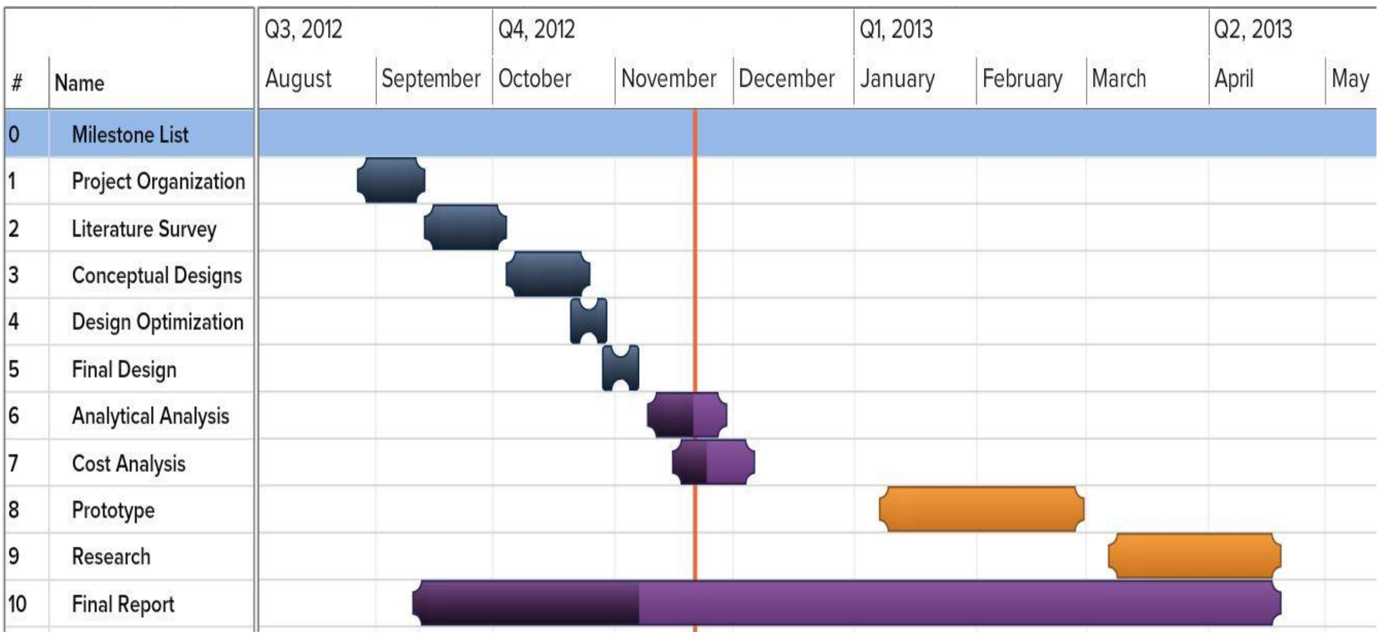

Figure 9: Gantt Chart

1.7 Analytical Analysis

While it may not be complicated to conduct motion studies in Solid Works, or stress and thermal analyses

1.8 Major Components

2.0 Structural Design

2.1 Cost Analysis

2.2 Prototype System Description

2.3 Prototype Cost Analysis

2.4 Plan for Tests on Prototype

2.5 Conclusions

2.6 References

[1] L. Liu1, J. Chen1, B. Zhu2, T.X. Yu2, X.M. Tao3 and J. Cao4
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[5] Lawson Hemphill
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