UNIVERSITI PUTRA MALAYSIA

SHEETING MECHANICS OF LAMINATED MATERIALS

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PROJECT REPORT IS SUBMITTED UPON THE PARTIAL

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ABSTRACT

The purpose of this research is to investigate the sheeting mechanic of the laminated material. The detailed mechanical behavior of plastic film is studied through some complex testing which includes uniaxial tensile test, tensile cyclic and stress relaxation test. The main objective of this project is to develop a low cost programmable tensile tester using LEGO Mindstorm system associated with the MATLAB function for mechanical testing of plastic film. A thin LDPE plastic film with a thickness of 0.01mm was selected as the specimen for the mechanical tests. In uniaxial tensile test, the LEGO tensile tester performed an uniaxial stretch of a sample while measuring the tensile force simultaneously. The results obtained from tensile tester were compared with the result obtained from texture analyzer. From the results obtained, the graphs of stress versus strain of the specimen are plotted to show their relationship. It was found that texture analyzer produced a noisy curve plot while LEGO tensile tester produced a smoother curve. The texture analyzer was able to stretch the plastic specimen until fracture point at 40m/m of strain, but LEGO tensile tester reached its maximum elongation of stretching at 0.6m/m of strain resulting in an unbroken plastic film. Besides that, the tensile cyclic and stress relaxation behavior of specimens was analyzed and discussed based on its mechanical characteristics. Finally, the results of this project were concluded and suggestions for improvement on further research were discussed.

ABSTRAK

Tujuan penyelidikan ini adalah untuk mengkaji mekanik pelapis bahan berlapis. Sifat mekanikal terperinci filem plastik telah dikaji melalui beberapa ujian kompleks yang meliputi ujian tegangan uniaxial, siklik tegangan dan ujian relaksasi tekanan. Objektif utama projek ini adalah untuk membangunkan penguji tegangan yang boleh diprogramkan dengan kos rendah menggunakan sistem LEGO Mindstorm yang dikaitkan dengan fungsi MATLAB untuk ujian mekanikal filem plastik. Filem plastik LDPE nipis dengan ketebalan 0.01mm dipilih sebagai spesimen untuk ujian mekanikal. Dalam ujian tegangan uniaxial, penguji tegangan LEGO melakukan tarikan sampel dalam satu arah sampel semasa mengukur daya tarik secara serentak. Hasil yang diperoleh daripada penguji tegangan dibandingkan dengan hasil yang diperoleh daripada penganalisis tekstur. Dari hasil yang diperoleh, graf tekanan berbanding tegasan spesimen telah diplotkan untuk menunjukkan hubungan mereka. Telah didapati bahawa penganalisis tekstur menghasilkan plot lengkung bising manakala penguji tegangan LEGO menghasilkan lengkung yang lebih lancar. Penganalisis tekstur dapat meregangkan spesimen plastik sehingga titik patah pada ketegangan 40m/m, tetapi penguji tegangan LEGO mencapai pemanjangan maksimum regangan pada 0.6m/m ketegangan yang mengakibatkan filem plastik tak terputus. Di samping itu, batasan tegangan dan tekanan kelakuan tegasan spesimen dianalisis dan dibincangkan berdasarkan ciri mekaniknya. Akhirnya, keputusan projek ini telah disimpulkan dan cadangan untuk pembaikan kajian lanjut telah dibincangkan.

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NOMENCLATURE

σ	Engineering stress
ε	Engineering strain
F	Force
A	Cross-sectional area
ΔL	increase in gage length
L_o	Initial length
E	Young's modulus

LIST OF ABBREVIATIONS

PET	Polyethylene Terephthalate
EVA	Ethylene-Vinyl Acetate
PE	Polyethylene
PS	Polystyrene
PC / ABS	Polycarbonate / Acrylonitrile Butadiene Styrene Blend
LDPE	Low Density Polyethylene
HDPE	High Density Polyethylene
ASTM	American Society for Testing and Materials
AC	Alternating Current
DC	Direct current
PC	Personal Computer
USB	Universal Serial Bus
RPM	Revolution per Minute
MATLAB	MATrix LABoratory

CHAPTER 1

INTRODUCTION

1.1 Overview

The food packaging technologies are improving consistently in response to the fast-changing social trends and the increasing customer demand for convenience and safety of food. The main objective of food packaging is to maintain the quality and safety of food products during storage and shipping, and to extend their shelf-life by avoiding unpleasant circumstances, such as hazardous microorganisms and their corresponding external physical forces, chemical compounds, sunlight, oxygen and moisture (Bradley, Castle, & Chaudhry, 2011). In order to accomplish such objective, packaging materials should arrange for physical protection to achieve an acceptable durability, as well as maintain the quality safety issues of food items. Therefore, selection of appropriate laminated material that used for food packaging is vital. Laminated material can be various types of plastic articles which comprise pre-cut pouches that laminated by the application of heat and pressure thereto by a laminator.

Mechanical behavior of the laminated material is crucial in designing and quality control in the packaging system. Hence, an ideal platform for the cost-effective prototype of tensile tester is primarily focused to allow detailed investigation in plastic film subsequently. Additionally, mechanical testing of the plastic film included uniaxial tensile strength test, tensile cyclic and stress relaxation test are conducted to study the behavior of the plastic film. It is also to further verify the result obtained from the newly developed tensile tester that able to provide accurate engineering measurements.

1.2 Research Background

Commercial laboratory equipment in the world today is expensive and often requires large investments. This had raised a significant problem in educational research with limited financial resources. Thus, building research equipment such as LEGO tensile tester enables development of scientific tools at lower costs that can deliver accurate measurements comparable with commercial laboratory equipment. (Moser et al., 2015).

In recent years the number of research on development of LEGO brick as a laboratory equipment has continuously increased. For instance, (Wang, LaCombe, & Rogers, 2004) addressed the utilization of LEGO programmable brick as a portable data acquisition system in their paper. On top of that, both programmable and non-programmable bricks have been used to teach engineering principles in tertiary level education (Whitman & Witherspoon, 2003). It indicated that the LEGO brick can become a powerful laboratory tool in the hands of engineers. Since the technology almost universally available, toy bricks are an ideal platform for cost-effective, rapid prototyping and related tasks, and for conducting sophisticated and reliable measurements.

In this project, LEGO Mindstorms EV3 technology is applied to develop a measurement device, namely a tensile tester that able to perform uniaxial, cyclic and relaxation tests respectively. The technology is chosen due to its active sensing and motion capabilities that satisfy the objective of this project. It demonstrates its potential for sophisticated tasks with the realization in LEGO of machinery that will be discussed in the next chapter.

The aim of this project is to develop a better performance of a machine compared to the commercial texture analyzer. Besides, it is to produce a lightweight, robust and reliable equipment for engineering testing. The uniaxial tensile test is one of the most fundamental engineering tests that provides valuable information about a material and its associated properties. These properties can be used for designing and analysis of engineering structures to develop new materials that best suit a specified use. The tensile tester is made up of plastic bricks along with the intelligent LEGO Mindstorms system and in combination with compatible third-party sensor solutions thoroughly fulfills the mentioned requirements.

1.3 Problem statement

Laboratory work presents not only intellectual but also financial challenges. Laboratory equipment is expensive and often need large investments. It requires more than RM 100,000 for its machine, a load cell with RM 10,000 and RM30,000 for software. Thus, an alternative is required to provide the solution for the current problem statement. Texture analyzer will be used as the equipment in this project. However, the result obtained might not be sensible for a small strength of the material despite its efficient and durability properties. It has been found that testing of film material using a commercial texture analyzer or Instron machine is inappropriate as the load cell is too large. The current equipment unable to produce a proper testing result due to the thin film properties. Besides, the equipment has the limitation on performing manipulation of complex deformation analysis, such as tensile cyclic and stress relaxation test.

Besides, detailed mechanical behavior of the film is not widely investigated. This includes complex testing such as uniaxial tensile test, tensile cyclic and stress relaxation test. The tests are crucial for effect of fatigue behavior on film material for food packaging application.

The research on the limitation of texture analyzer is scarcely available in the recent academic studies. Therefore, some assumptions are made based on the available information to carry out further development.

i. The newly developed tensile tester can provide a reliable and accurate mechanical testing result compared to the texture analyzer when the lightweight and low strength specimen is being tested.

ii. The tensile tester can provide the data and result similar to the theory of standard testing such as tensile cyclic test and stress relaxation test. This proves that integration between duplicate engineering knowledge and the programmable device is highly possible.

1.4 Research scope

The research scope of the project is to develop a cost-effective tensile tester for testing thin film that allows for accurate measurements and comparable to that of standard laboratory equipment, texture analyzer. Besides, assembly of a tensile tester is crucial for its high load cell sensitivity to provide a better result than the texture analyzer. The tensile tester has the capability to perform complex deformation analysis, such as tensile cyclic and stress relaxation test on thin film. Hence, the mechanical properties of the plastic film will be studied through three different tests which are uniaxial tensile test, tensile cyclic and stress relaxation test.

1.5 Objectives

The objectives of the project are:

i. To build and develop a programmable tensile tester using LEGO Mindstorm system associated with the MATLAB function for mechanical testing of plastic film

ii. To test and compare the result between the tensile tester and texture analyzer through the uniaxial tensile test.

iii. To study the behavior of the plastic film by using the newly developed tensile tester (see objective 1) through tensile cyclic and stress relaxation test.

1.6 Thesis structure

The thesis consists of five chapters. Chapter 1 gives the introduction of the project. The chapter includes overview, problem statement and objectives of this project. Chapter 2 is the literature review of the project on lamination, plastic film and some mechanical tests. This is followed by Chapter 3 that explain the methodology of the project in details. Chapter 4 shows the results and discussions of the experiments while conclusion and recommendations were given in chapter 5 for further related research.

CHAPTER 2

LITERATURE REVIEW

A review of the literature is carried out based on the research finding, theory work and testing techniques.

2.1 Lamination

A literature review on the thickness of laminates and temperature required to produce a laminated material was studied. This section is important for determining a suitable plastic film thickness as a material for this project. Lamination can be done with various types of plastic articles which comprise precut pouches that laminated by the application of heat and pressure by a laminator. It contains a harder layer on the outside and the softer layer on the inside (Figure 2.1). When both layers combined, it makes up the micron thickness. A micron is a thousandth of a millimeter (0.001 millimeters). Usually the overall thickness of laminates is within 150 to 300 microns (Martini, 1986). The harder outer layer is usually made from PET plastic (Polyethylene Terephthalate) and the softer inner layer is made up of EVA plastic (Ethylene-Vinyl Acetate).

Occasionally a combination of PET plastic, PE (Polyethylene Plastic) and EVA plastic are all used together.

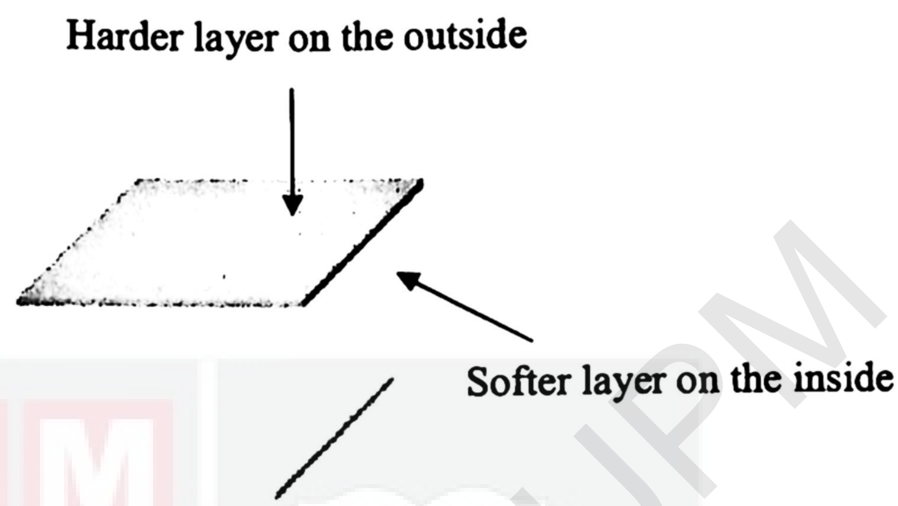


Figure 2.1: Schematic diagram on the plastic pouch

In order to produce a durable and usable laminated material, (Hun Lee, 1998) mentioned that pouch laminator typically uses a high temperature film as its coating film. The writer emphasized that at least one heating roller installed in the laminator must be heated to a high temperature of not less than 150° C.

2.2 Multilayer packaging film

(Marynissen, 1998) established a multilayer film that built up the following layers, an inner layer of linear medium density polyethylene, a fourth intermediate layer of medium density polyethylene, a fifth intermediate layer of medium density polyethylene and outer layer of linear medium density polyethylene. The overall thickness of the film were amounted to 350μm. Such multilayer packaging films are used for the manufacture of packaging, for instance, foodstuffs and personal care products. Marynissen indicated that the packaging manufactured from such film should have a certain flexibility, rigidity and compressibility. So that, it guarantees a good stability of the shape of the packaging.

2.3 Plastic film

The plastic film is a thin continuous polymeric material. It functions as barriers to keep liquid or gas on one side of the film, which is useful in packaging applications. The concern is on the permeation properties and strength of the plastic film to withstand impact forces when loads is applied. Low Density Polyethylene (LDPE) is a low density, semi-crystalline and thermoplastic polymers. (Xu, Huang, Feng, McShane, & Stronge, 2016). LDPE film has a softer feel and shinier appearance compared to High Density Polyethylene (HDPE). It has very high elongation properties that is suitable to stretch wrap application. Thus, standard plastic tests of the American Society for Testing and Materials (ASTM) is used to investigate its mechanical properties. The review of the mechanical tests will be discussed in the section later.

2.4 LEGO Mindstorm in educational research

According to Luo , Z & Pollack, R. (2006), LEGO is an interactive proof system that extensively used by many people. For instance, LEGO Mindstorms robots were introduced as hands -on educational technology for undergraduate students that attended computer engineering courses (Williams, 2003). Students show favoritism towards learning Lego Mindstorm robots in their courses. Besides, it has shown a high interest among engineering students by using LEGO Mindstorms NXT kits and LabVIEW in lab work on Mechatronics related subjects (Gómez-De-Gabriel, Mandow, Fernández-Lozano, & García-Cerezo, 2011).

Furthermore, Soft Matter Physicist Richard Moser demonstrated the testing of his wearable electronics by using Lego blocks in the lab. He also produced his best master thesis on development of such a device simply from kid's toys, together with a few common parts.

2.5 Mechanism of tensile tester

There is a documentation for a tensile testing setup built from LEGO toy bricks that available on the official website (http://www.somap.jku.at/ltt/) as an open source for researchers or students to replace commercial tensile testing machines and as a demonstration device in practical courses in physics or engineering.

A literature review on the mechanism of tensile tester was studied. Some main elements in the fabrication of tensile tester consist of: 2 Electric Motor – NXT (Figure 2.2a), a Mindstorms NXT (Figure 2.2b) , 2 Electric Touch Sensor – NXT (Figure 2.2c) and some LEGO Technic parts. Technic parts are essential to provide the necessary mechanical stability to the frame of the tensile tester machine. The entire LEGO tensile tester was made up from 89 components. There were elements not made from toy bricks which included the acquisition board, the clamping device and the digital caliper (Moser et al., 2015).

The toy brick tensile tester can perform measurement of stress-strain and resistance/ strain progression where evaluation of static material properties such as Young's modulus, Tear strength, Fracture and other properties can be achieved. (Figure 2.3)

Figure a Figure b Figure c

Figure 2.2 : Components of tensile tester

(Source: Legocom. 2018)

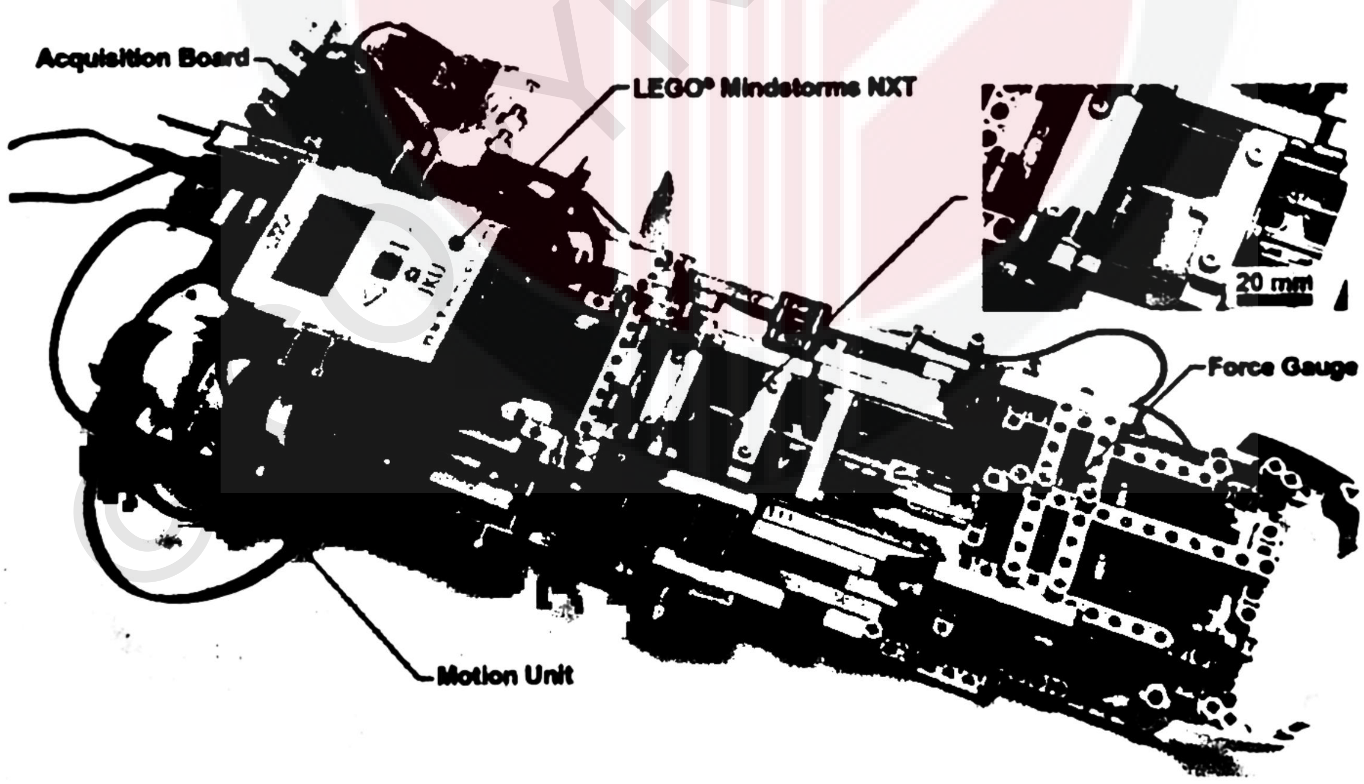


Figure 2.3: Photo of the toy-brick tensile testing setup

(Source: Moser et al., 2015)

2.5.1 Data acquisition

A data acquisition board records strain, force, and resistance readings and delivers these data packages on request to the NXT. The NXT then transfers the data via a USB connection to a LabView user interface (National Instruments, USA), where the final data visualization and analysis are performed. The permanent data flow allows adjustment of all measurement parameters at run time and enables real-time tracking of the data obtained. These recordings can be gathered either by manual control of the measurement procedures or by executing predefined sequences.

2.5.2 Gripper

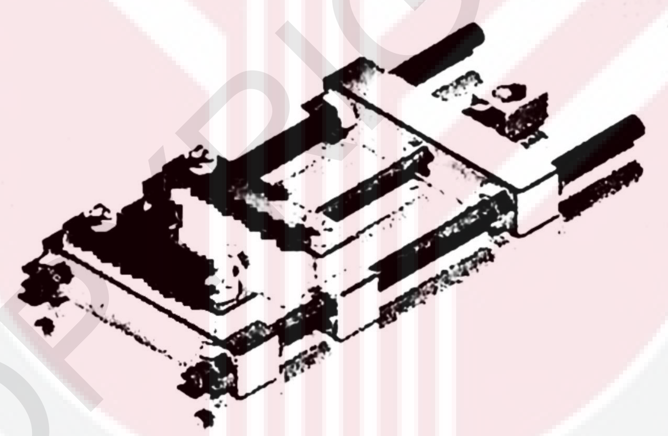


Figure 2.4: Assemble gripper

(Source :Legocom ,2018)

According to the open source, the gripper used is made from aluminum whereas the clamping blocks were manufactured by milling (Figure 2.4). The guidance rods and the clamp fixation for the force gauge are standard M3 and M4 threaded rods affixed with M3 and M4 bolts and nuts. Thread rods and fixation parts purchased in hardware-shop. The individual parts were designed using Solid Works. The finished gripper is then simply placed into the LEGO frame with the front clamp sitting in the moving sledge (Figure 2.5).

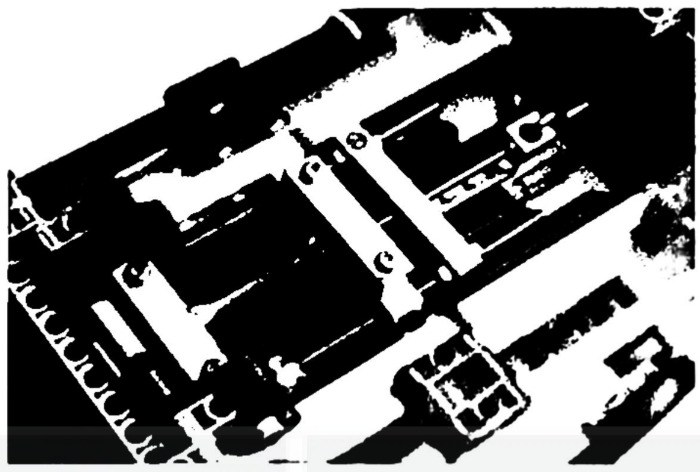


Figure 2.5: Placing of gripper

(Source: Moser et al., 2015)

2.5.3 EV3 Brick

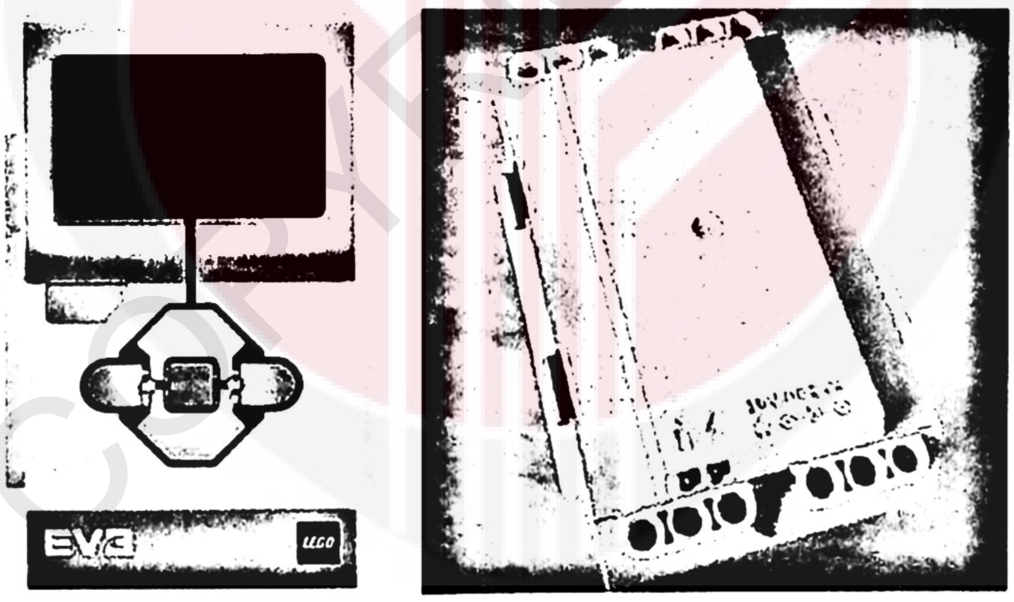


Figure 2.6: Front and back views of the EV3 Brick. The back is the 10V battery

(Source: Rollins, 2014)

EV3 Brick with element number 6009996 is a computerized and programmable brick. It can carry out its specific functions by defining the correct command through the programming language of EV3. Figure 2.6 shows that the buttons on the north, west, south, and east positions are the controls for up, left, down, and right, respectively. The key in the center works as an "enter" key, and the key directly under the left side of the screen is the "back" button. Shown on the right side of Figure 2.6 is the rechargeable battery pack with element number 601282. It comes with the Core Set and takes the place of 6 AA batteries. The battery pack is very easy to install and can charge via AC outlet with the included cord.

Figure 2.7: The other sides of the EV3 Brick

(Source: Rollins, 2014)

Next, there are four ports on each of the north and south sides of this brick (Figure 2.7). These ports have specific purposes. Input ports 1-4 located on the north side, are used to connect the sensors, while the output ports labeled A-D located on the south side, are made for the motors. Connector cable is used to attach between the motor and sensor to the ports of EV3 Brick. There is also a micro USB port labeled "PC". A USB cable that available in the Core Set is used to attach to a computer that allow programming the EV3 Brick from PC (Rollins, 2014).

2.5.4 EV3 Large Servo motor

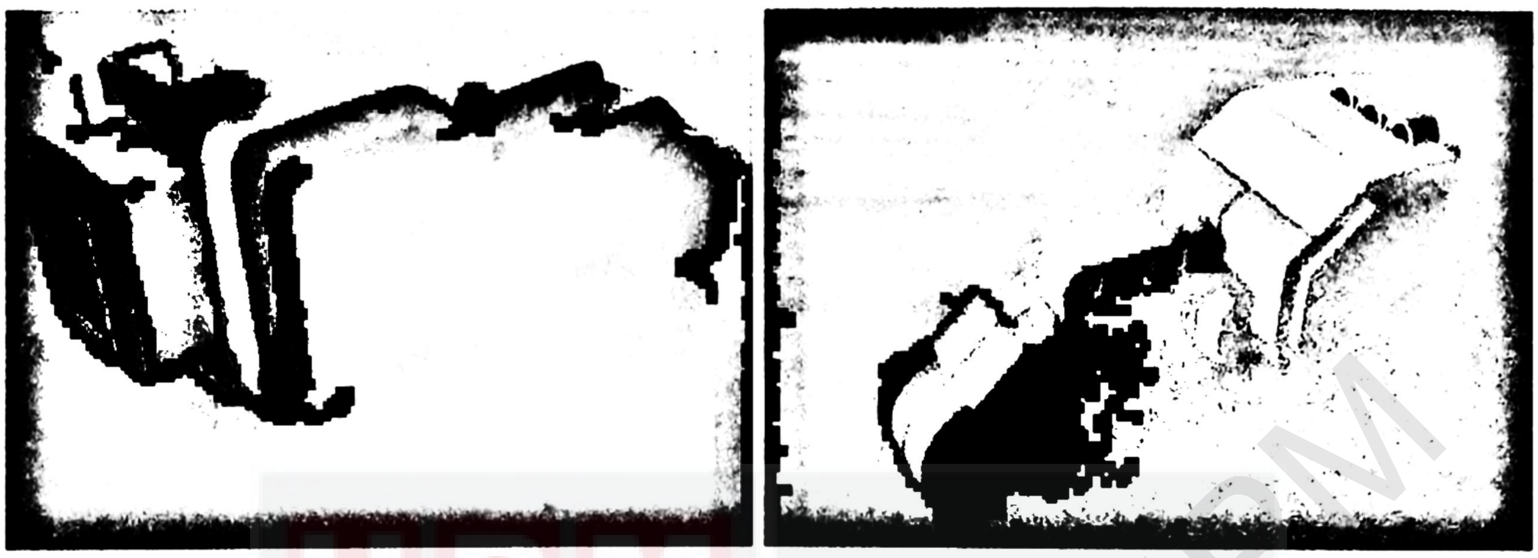


Figure 2.8: Two views of the Large Motor

(Source: Rollins, 2014)

The EV3 Large Servo Motor is a powerful motor that uses tacho feedback for precise control to within one degree of accuracy (Figure 2.8). By using the built-in rotation sensor, the intelligent motor can be made to align with other motors on the robot so that it can drive in a straight line at the same speed. It can also be used to give an accurate reading for experiments. The motor case design also makes it easy to assemble gear trains. The motor has 160 to 170 RPM with running torque of 20 N.cm and stall torque of 40 N.cm. (Legocom, 2018).

2.5.5 Touch Sensor

Figure 2.9: The front and back view of a Touch Sensor

(Source :Rollins, 2014)

The analog EV3 Touch Sensor with element number 6008472 is a simple but exceptionally precise tool that detects when the red button is pressed or released. It can be programmed to do something when pressed, which comes in handy for stopping or starting actions (Figure 2.9). This button can also be set up for doing actions when the button is released as well as pressed. Another set-up can include something on when the action is "bumped" (Rollins, 2014). It also can count single and multiple presses.

2.5.6 Load cell

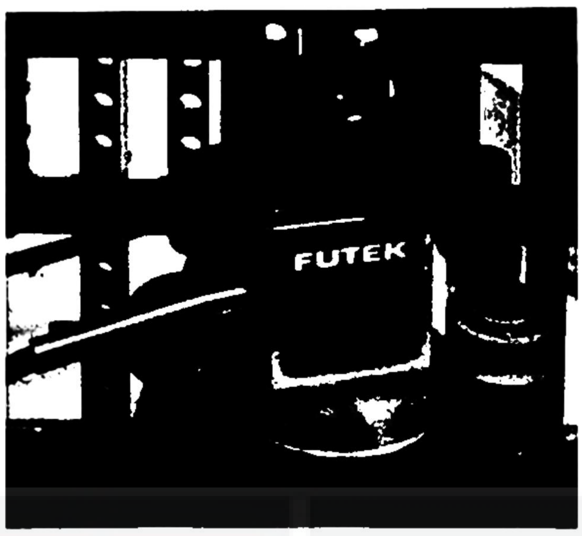


Figure 2.10: Load cell

A load cell is defined as a transducer that converts an input mechanical force into an electrical output signal. It is a highly accurate device that is used to measure weight or force in several different applications. They can be used to measure compression, tension, bending or shear forces. Within the load cell structure is an area, or group of areas, which are designed to be stressed when a load is applied, normally in a linear fashion. Strain gauges manufactured from metal foil are bonded to these areas to sense the strain in the load cell structure under the applied load or pressure, and then provide an electrical output signal proportional to the strain when excited by a regulated voltage or current source. This signal is usually only a few millivolts and usually requires amplification before it can be read (Lcmsystemscom, 2018).

The load cell used for this project is shown in Figure 2.10. It is manufactured in US by FUTEK Advanced Sensor Technology (FUTEK), a leading manufacturer producing a huge selection of Load Cells, utilizing one of the most advanced technologies in the Sensor Industry.

2.6 Mechanical tests

2.6.1 Uniaxial tensile strength test

The uniaxial tensile test is a basic engineering test to measure mechanical properties of a material. It involved mounting a specimen in a tensile testing machine and subjecting it to tension by applying longitudinal or axial load at a specific extension rate till failure. A typical tensile test specimen in dumbbell shape is shown in Figure 2.11.

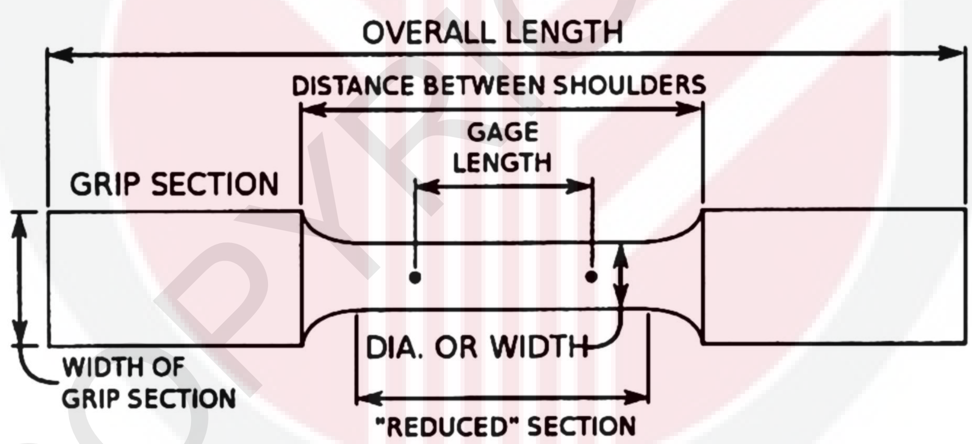


Figure 2.11: A typical tensile test specimen

(Source : Joseph R. Davis, 2010)

The tensile force is recorded as a function of the increase in gage length. The tensile force – elongation data is used to plot a stress- strain curve as shown in Figure 2.12. Stress is usually measured in N/m^2 or Pa, such that 1 N/m^2 = 1 Pa. From the experiment, the value of stress is calculated by dividing the amount of force (F) applied by the machine in the axial direction by its cross-sectional area (A), which is measured prior to running the experiment. Mathematically, it is expressed in Equation 1. The strain values, which have no units, can be calculated using Equation 2, where ΔL is the is the increase in the gage length of the specimen and L_o is the initial length.

$$\sigma = \frac{F}{A} \qquad \text{(Equation 1)}$$

$$\varepsilon = \frac{\Delta L}{L_o} \qquad \text{(Equation 2)}$$

The important parameters that describe the stress-strain curve obtained from tensile test are ultimate strength, yield strength, percent elongation, area of reduction and Young's modulus.

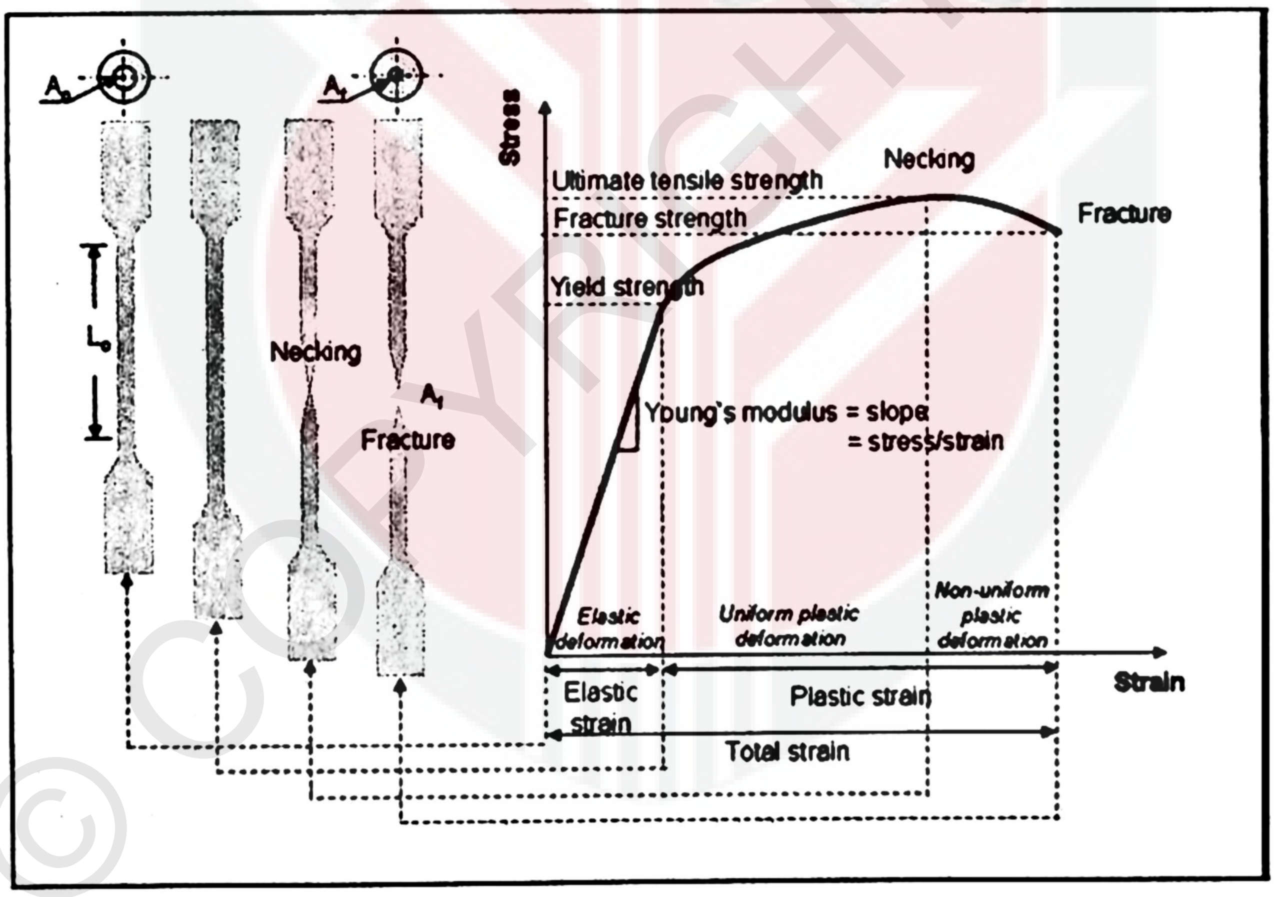


Figure 2.12: Typical stress- strain curve for a tensile test

(Source :American Journal of Civil Engineering and Architecture, 2014 2 (1), pp 53-59)

There are two regions in the stress –strain curve, which are elastic strain region and plastic strain region. In elastic region, the material returns to the undeformed state when applied forces are removed. During elastic deformation, the engineering stress-strain relationship follows the Hook's Law and the slope of the curve indicates the Young's modulus (E). In plastic region, the material deforms permanently where it unable to recover to its original shape. Necking occurred when a material reaches its ultimate stress strength of the stress-strain curve, at the same time its cross-sectional area reduces dramatically.

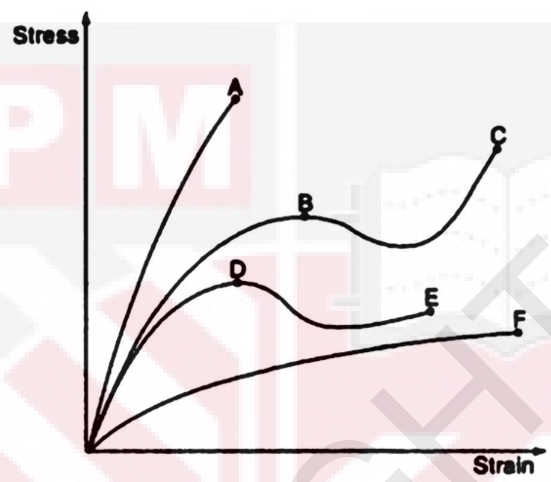


Figure 2.13: Typical engineering tensile stress vs. engineering strain curves for different characteristic of materials

(Source :Mark, 2007)

Based on Figure 2.13, points A, C, E, and F correspond to the tensile strength and elongation at break, D and B at yield. The curve ending at A represents a brittle material, those with C and E are tough materials, each with a yield point, while the curve ending in F shows a tough material without a yield point (Mark, 2007).

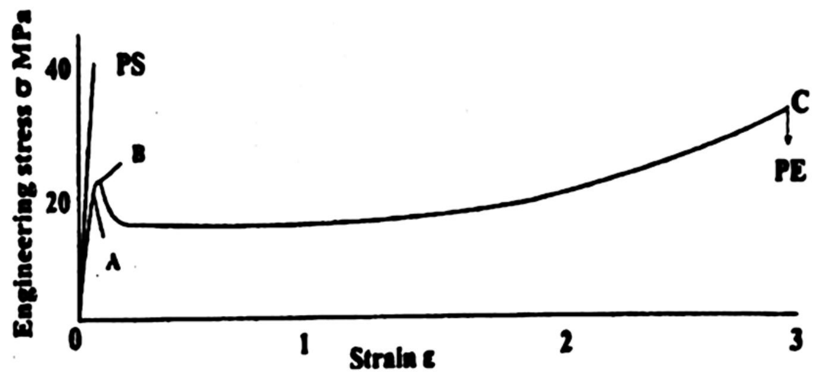


Figure 2.14: Stress- strain curves for polystyrene (PS) and polyethylene (PE)

(Source: D.Symposium, 2012)

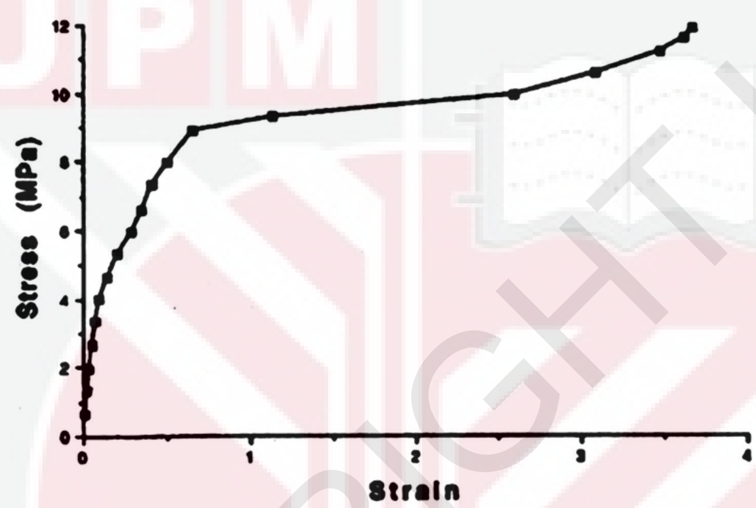


Figure 2.15: Stress- strain plot for polyethylene

(Source: Carter Gilmer, T. & Williams, 1996)

The concern of the experiment is to determine the stress- strain curve for a polymer. Hereby, Figure 2.14 shows the typical Stress- strain curves for polystyrene (PS) and polyethylene (PE) from the research work of D. Symposium. The PE behaves as a linear elastic solid from 0 to point A where this region is regarded as Young's modulus (E). Point B is known as the yield point and it indicates the onset of plastic deformation. From B to C, it is the plastic region. Beyond B the material stretches out considerably and a "neck" is formed (D.Symposium, 2012). Figure 2.15 shows another result obtain from Carter Gilmer, T. & Williams, (1996)

2.6.2 Tensile cyclic loading test

The tensile cyclic test is to investigate the effect of stress level on the fatigue behavior of a material. According to (Da Costa Mattos & Martins, 2013) ,a closed stress-strain loop is obtained where the strain is cycled between the two values during constant amplitude cycling. The loop is known as hysteresis loop as illustrated in Figure 2.16.

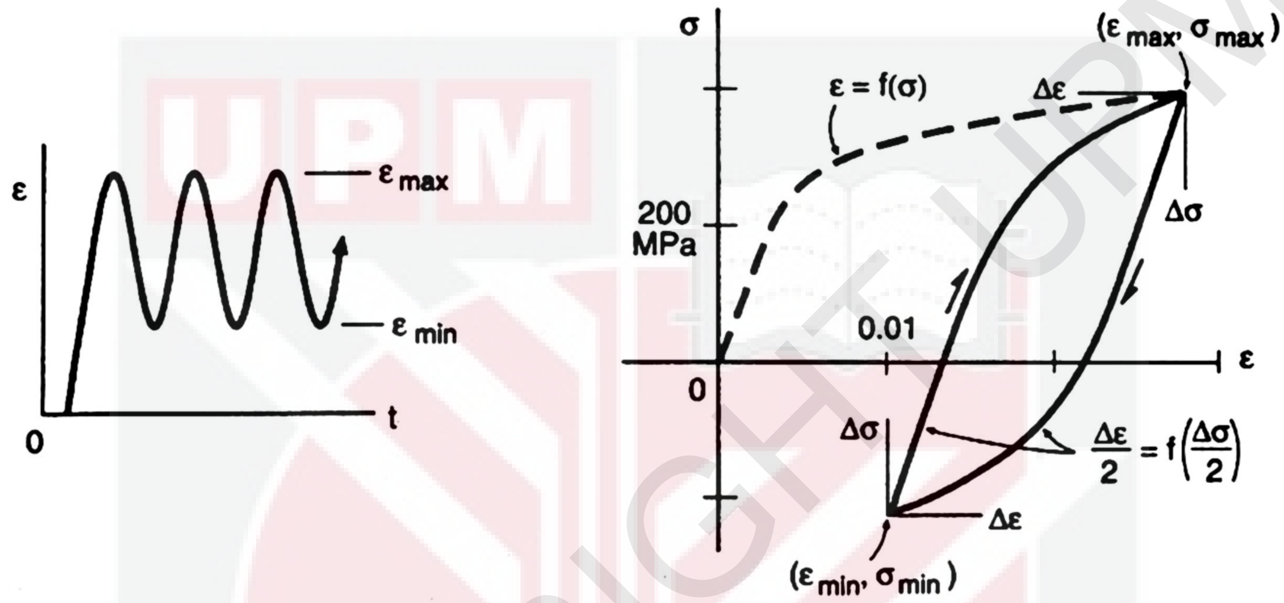


Figure 2.16: Stress and strain unloading and reloading behavior consistent with a spring and slider rheological model

(Source: Da Costa Mattos & Martins ,2013)

(Fang, Wang, Beom, & Li, 2008) studied the effect of cyclic loading on tensile properties of PC and PC/ABS with several tension-tension loading cycles of 1,3,5 and 15 cycles. The dumb-bell tension specimen specimens are first loaded with a crosshead speed of 1 mm/min, then unloaded and reloaded with the same crosshead speed for a predetermined number of cycles until failure. Figure 2.17 showed a loading curve with 15 loading cycles from their research work.

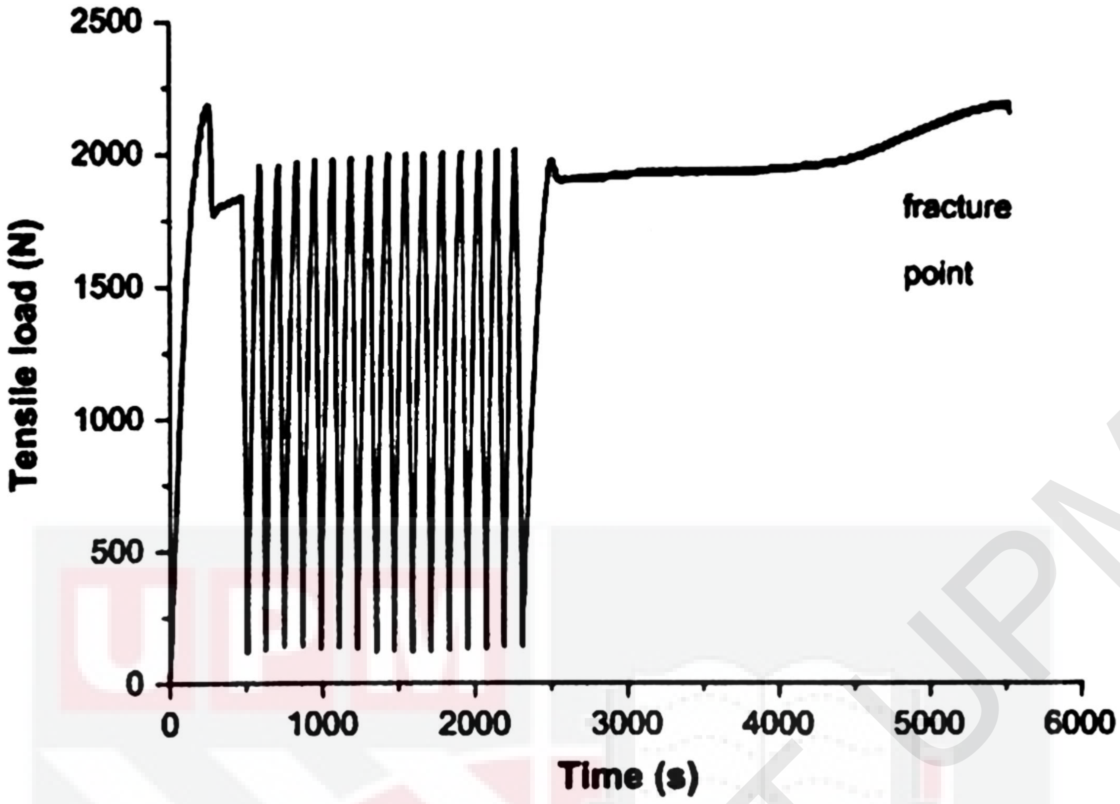


Figure 2.17: Cyclic loading curve

(Source: Fang, Wang, Beom, Li, 2008)

2.6.3 Stress relaxation test

Stress relaxation is defined as a gradual decrease in stress with time, under a constant deformation namely strain. This characteristic behavior of the polymers is studied by applying a fixed amount of deformation to a specimen and measuring the load required to maintain it as a function of time. (Shah Vishu, 2007)

At the beginning of the experiment, the strain is applied to the specimen at a constant rate to achieve the desired elongation. Once the specimen reached the maximum stress, the strain is held constant for a predetermined amount of time. At this stage stress decay, which occurs due to stress relaxation with time. The stress values at different time intervals are recorded and the results are plotted to obtain a stress versus time curve as shown in Figure 2.18. The stress relaxation experiment is often carried out at various levels of temperature and strain.

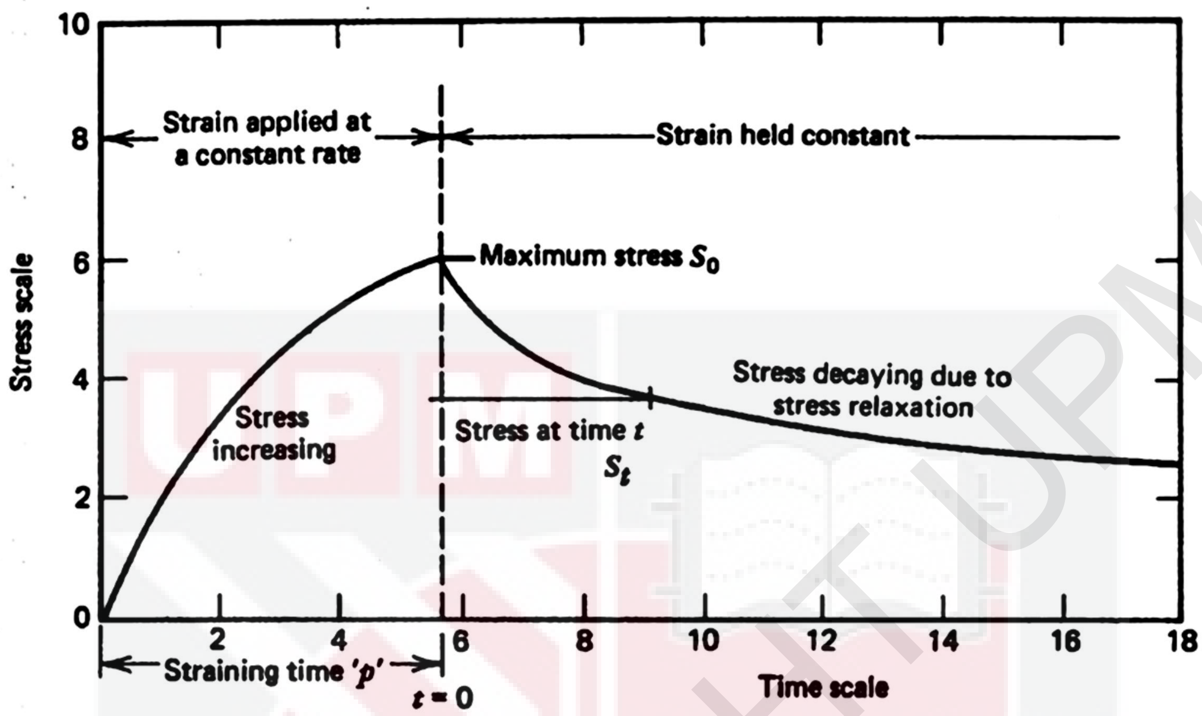


Figure 2.18: Stress–time curve.

(Source :Courtesy of Instron Corporation cited by (Shah Vishu, 2007).)

CHAPTER 3

METHODOLOGY

3.1 Materials and equipment

The equipment and apparatus used are Texture Analyzer model TA-XT Plus (Stable Micro System Ltd.UK) and newly developed tensile tester.

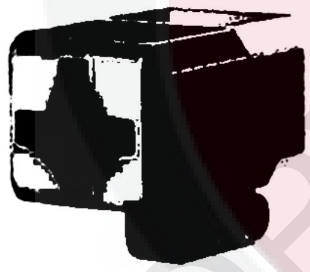
3.2 Development of LEGO tensile tester

3.2.1 LEGO structure design and assembly

Building of the measurement device is by using the LEGO Mindstorms EV3 robotics set. It included the LEGO elements, motors and intelligent sensors. A draft is prepared prior to creating the measurement device. The motors and sensors are assembled to add movement along with the MATLAB software application. The LEGO Mindstorm set is applied to the setup for its simplicity, mechanical stability and adaptiveness that capable of delivering an accurate and trustworthy results.

The device performs an uniaxial stretch of a low-density polyethylene sample while measuring the tensile force simultaneously. The objective of the design was to fabricate a low-cost tester that allows duplicate knowledge in mechanical or electrical engineering. The test data provide key quality control checks for materials related to the food packaging system. The main components of the device were shown in Table 3.1.

Table 3.1: Main component of the measurement device

Component	Name
	LEGO EV3 Programmable Brick
	Linear actuator
	Touch sensor
	Large motor
	Connector cable

As shown in Table 3.1, the LEGO EV3 Programmable brick serves as the central control unit and power station of the device. During the measurement, the force is evaluated synchronously by FUTEK load cell and it is connected to computer via USB port. The data obtained by those “intelligent sensors” is sent on request to the EV3 Brick, which itself also acts as a communication device to the MATLAB interface where the final interpretation, acquisition and recording of the measured data and control is performed.

To measure the tensile force the setup contains a FUTEK load cell which is fixed and stable mounted on the LEGO frame, with its sensor post being mechanically conjoined via a M3 screw with the clamp. The second clamp is mechanically connected to the linear actuators allowing for uniaxial stretching of the sample either in upward or downward movement. The actuator is driven by a LEGO EV3 motor with subsequent gearing. Front view and back view of the device were shown in Figure 3.1 and 3.2.

Figure 3.1: Front view of Lego device

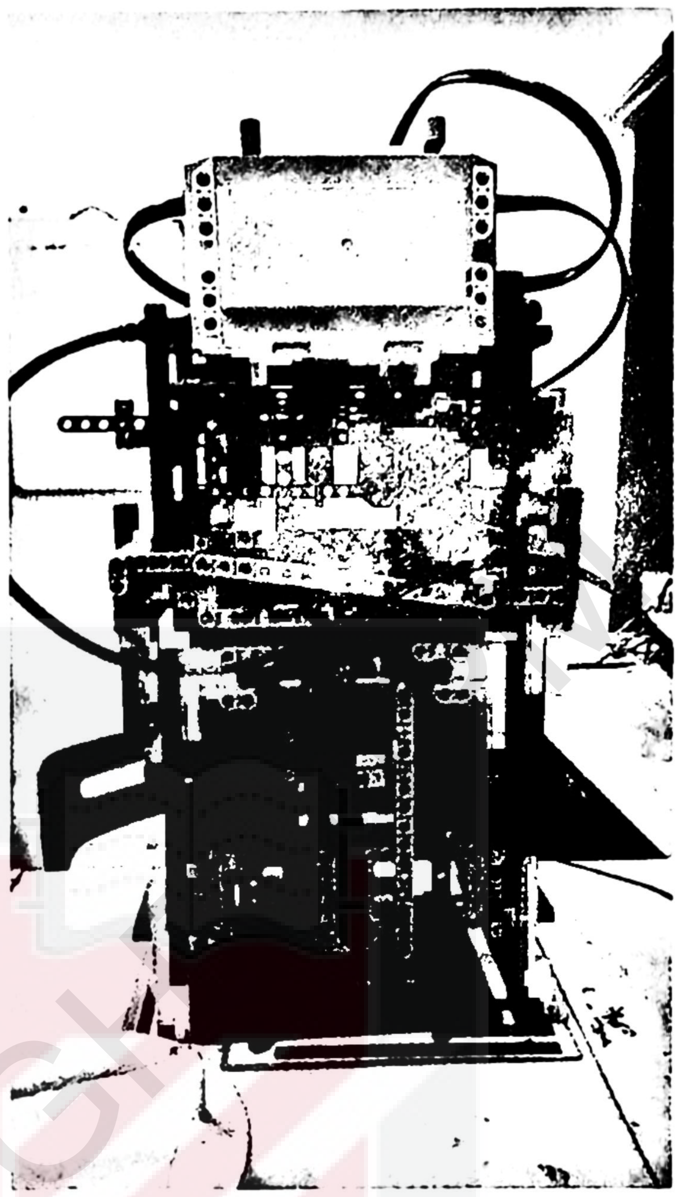


Figure 3.2: Back view of Lego device

3.2.2 Sample Clamping and Stretching

Uniaxial extension is needed to record the strain and tensile force progress. Thus, only one-dimensional movement is necessary to determine the stress-strain curves of polymer. It is performed by LEGO linear actuators, which convert the rotary motion of the working LEGO motors and the following gearing into a concurrent linear motion. The actuator shown in the center of Figure 3.1 allow a displacement of 11mm and are conjoined to the sample grip as shown in Figure 3.4. To prevent the linear actuators from reaching their drive-limitations, 2 sensors are located each at above and bottom to stop the motors immediately when triggered.

The used LEGO motor controls the velocity of the actuator. The Inbuilt and external gearing increases the output torque (Moser, 2015). The MATLAB allows to configure the speed of the motor in the range of 0-100%. Thus, the linear motion of the actuator is performed with defined velocity to obtain comparable and reproducible results. However, the motor shows different speeds in their rotational directions, resulting in different velocities for stretch and relaxation of the specimen.

The stable clamping of the specimen, is a crucial and maybe also a controversial part of the device. Although it was intended to use only LEGO parts for the device's framework, it remained impossible to guarantee a proper clamping of the samples. It was simply not possible to mount the samples without slippage. Therefore, a rubber contraption had to be used. However, in order to completely avoid sample slippage blue tack has to be attached to the side of the grips to fix the position of the clamp. Figure 3.3 shows the clamping contraption embedded in the LEGO frame.

Figure 3.3: Setup of clamp

Figure 3.4: Specimen attached to the clamps

Basically, the clamping consists of two parts. The sample grips and a linking bar to ensure directional stability during movement. One clamp is directly conjoined to the clamp of the FUTEK sensor and remains fixed during stretching of the specimen. The other clamp is steadily mounted onto the actuated sledge (Figure 3.4). Furthermore, this solution offers the possibility for a well-defined tightening torque. The polymer specimen with blue tack attached is rolled over the clamp at both ends to maintain its rigid position and prevent slip off situation during the test. When test starts, this leads to a significant change in sample length due to the resulting Poisson-stress.

3.2.3 MATLAB implementation

A series of MATLAB command is created to add movement to the LEGO measurement device. This is done by using MATLAB software to generate coding for tensile tester. Several m files were created, it includes the tensile, relaxation and cyclic m file. Each file has its own command to the system. The device is used in combination with the MATLAB programming to allow iterative analysis on the mechanical test of plastic film.

MATLAB is a programming system that offers a direct control mode on the measurement device where the actual program is running on a computer. It requires the connection of the Programmable Brick and FUTEK sensor to the computer through USB. It provides real time control and data presentation by giving commands in the MATLAB. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms and the creation of user interfaces that is very useful in this project.

A set of coding is written in the MATLAB command box which consists of 3 tests mainly tensile, cyclic and relaxation tests (see Appendix A, B and C). Basically, MATLAB acts as a communication bridge between the user interface and the actual measurement device. It involves 3 platforms between user, computer and LEGO tensile tester. The user gives command by giving appropriate control or adjusting measurement parameters to the tensile tester to begin the testing. When the test started, it allows real time tracking of the obtained data and display real time graphical visualization of force-time data (Figure 3.5). The data are recorded in a table by executing the predefined command. Those data recording can be saved in other software for further analysis.

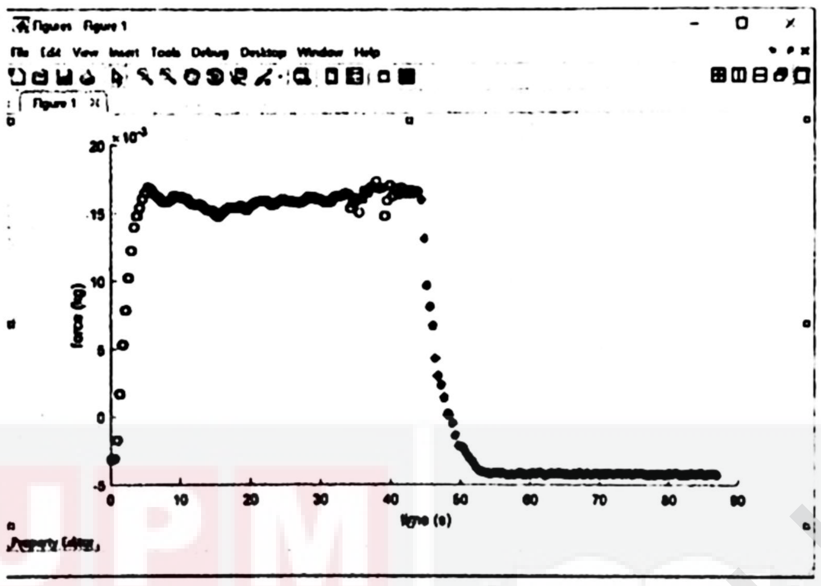


Figure 3.5: Graph generated during experiment of tensile test

It consists of command script for user input and LEGO part. It starts with the connection of FUTEK USB that attached the FUTEK sensor to the computer (Figure 3.6). The script file then requires the user to enter process type which determines the test to be performed. The process type included down, up, tensile, relaxation and cyclic. When one of the process type is entered, the user interface indicates the following commands to be executed. The flowchart of the process is shown in Figure 3.7.

Figure 3.6: FUTEK sensor

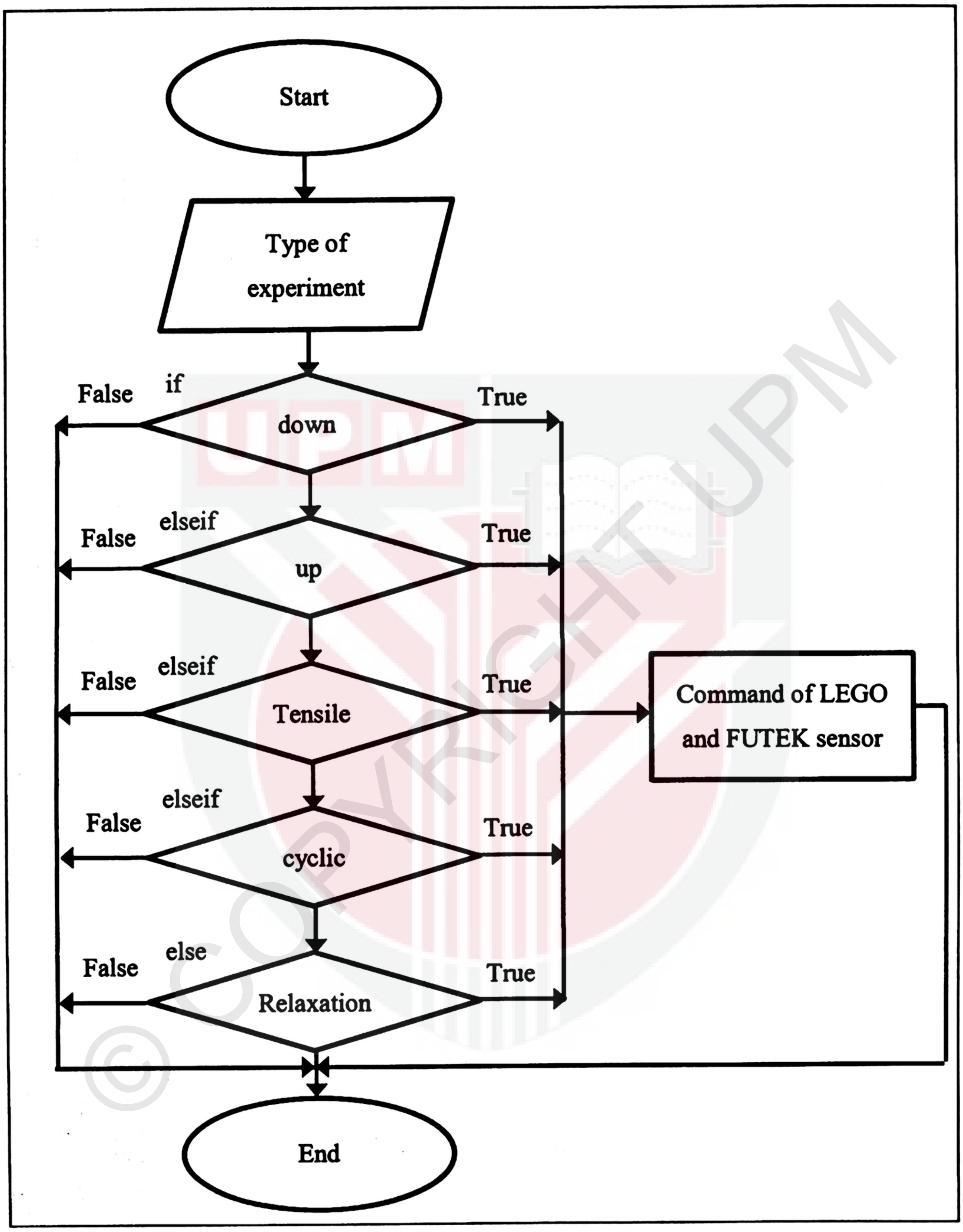


Figure 3.7: MATLAB Flowchart of the type of experiment in LEGO tensile tester

3.2.4 Motor mechanism

The type of motor used for the tensile tester is EV3 Large Servo Motor. There are five modes of input values for motor settings. These modes define the duration of motor movement namely, Off, On, On for seconds, On for Degree and On for rotations. The off mode is to stop the motor. The on mode is used to turn on the motor and it must work with other command to determine the duration of on mode of motor. In this project, the motor is set to run with on mode and stop when the touch sensor is pressed making it act as an 'off switch'. On for seconds mode also used in this project where the motor is turned on for the second that have assigned to it. The next mode is the On for Degrees mode. The degree defines the number of degree that the motor turns. It ranges from 0° to 360°. The last mode is On for rotations mode that works similarly to the On for Degrees mode except that it can be set up on how many rotations for the motor to turn.

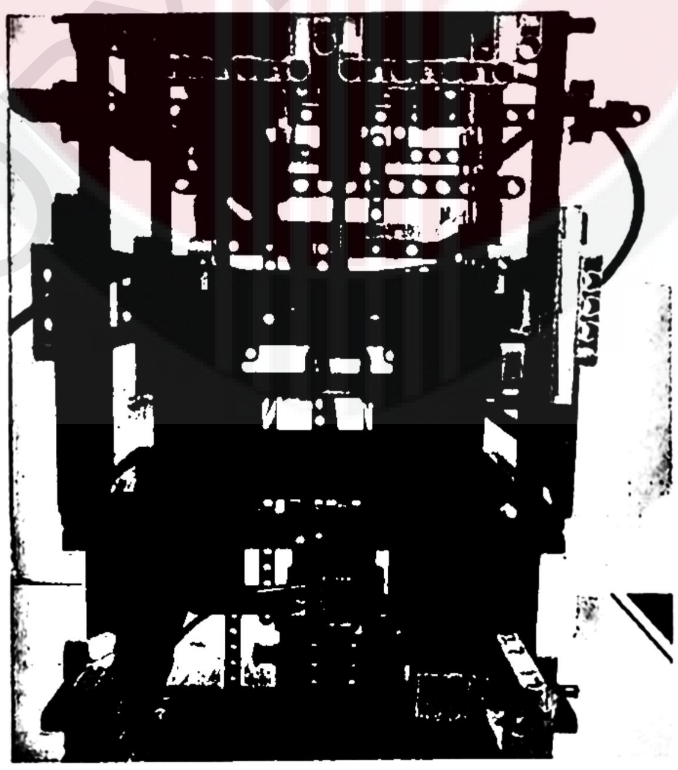


Figure 3.8: Location of touch sensors

In short, the motor mechanism that used in the project are On and on for seconds mode. The On mode is used in uniaxial tensile test to allow maximum elongation of film specimen without damaging the actuator. On for second mode is used in both tensile cyclic and stress relaxation test to determine the behavior of the film specimen at certain period. Figure 3.8 shown the touch sensors located each at above and bottom of test area to detect signal when it is pressed. Power input of motor ranges from 0 to 100%. Higher number gives faster speed to the motor.

3.2.5 Modification and pilot run

Integration of sample clamping and stretching, MATLAB implementation and motor mechanism, the tensile tester is constructed as a platform of mechanical testing device. Some modifications have been made from the previous work of Richard Moser. The author built a horizontal tensile tester that able to stretch the sample at constant velocity. He used force gauge to detect the load applied. Two motors were used in his design. A LEGO Mindstorm NXT and acquisition board is used. It can stretch material samples uniaxially with traveling distances of up to 30 mm while measuring the tensile force less than 30 N. (Moser et al., 2015)

For my device design, some modifications have been done based on the original design of Richard Moser to suit my purpose of the project. Sensors were located each at above and bottom of the clamping contraption. A large motor is used to drive the motion of linear actuator either to lengthen or shorten the distance. A FUTEK load cell is used to measure force applied as it can be used for tensile and compression application.

MATLAB application is used to replace the Labview software in this project. The tensile tester is developed similar to the function of a texture analyzer that it can stretch the specimen in upward or downward position.

An overall image of the pilot run, it begins with clamping of the film specimen at the clamping contraption. One end of the clamping section connects the actuator that is driven by the large motor while the other end of clamping section conjoined with the FUTEK load cell that connect to the PC via USB port. When the MATLAB command begins, the motor receives signal from PC and start to move accordingly. The tensile force is detected by the FUTEK load cell and a real time data tracking and recording is conducted simultaneously. When one of the touch sensor is pressed, the motor stopped, and testing ended. The data obtained can be used for further analysis.

3.3 Sample preparation

One type of material is used for the experimental work. A commercial, soft and flexible LDPE was purchased in the market. The thin, flat LDPE plastic material was machined into a standard dumbbell-shaped test specimen according to the proper dimension in ASTM D638 standard (Figure 3.9).

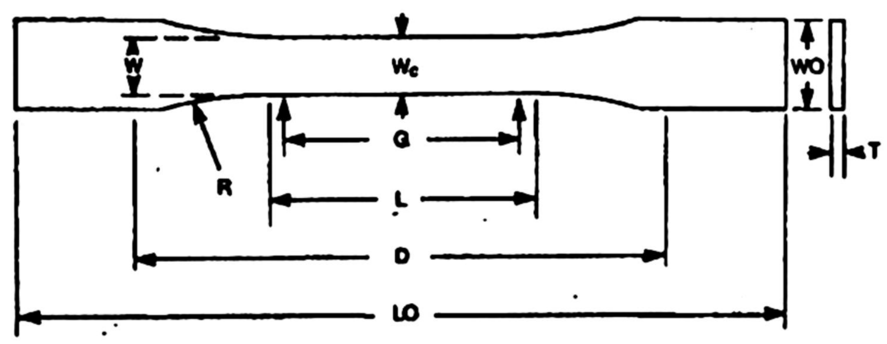


Figure 3.9: A typical dumbbell-shaped test specimen

(Source: ASTM D638)

Table 3.2: Dimension of the specimen

Dimensions	mm
W - Width of narrow section	2.00
L - Length of narrow section	9.53
WO - Width overall, min	9.53
LO - Length overall	63.5
G - Gage length	7.62
D - Distance between grips	25.4
R - Radius of fillet	12.7

3.4 Mechanical Test Analysis

To investigate the compatibility of the newly developed tensile tester, experimental result of texture analyzer and tensile tester were compared. Mechanical tests stated in the research are conducted to further evaluate the performance of tensile tester.

3.4.1 Uniaxial tensile test on texture analyzer

Uniaxial tensile tests were performed by using a texture analyzer (TA-XT) model (see Figure 3.10). The standard dumbbell-shaped test specimens were prepared according to the dimension specified by ASTM D638 standard test method as described in the Table 3.2.

Figure 3.10: Experimental photos of texture analyzer

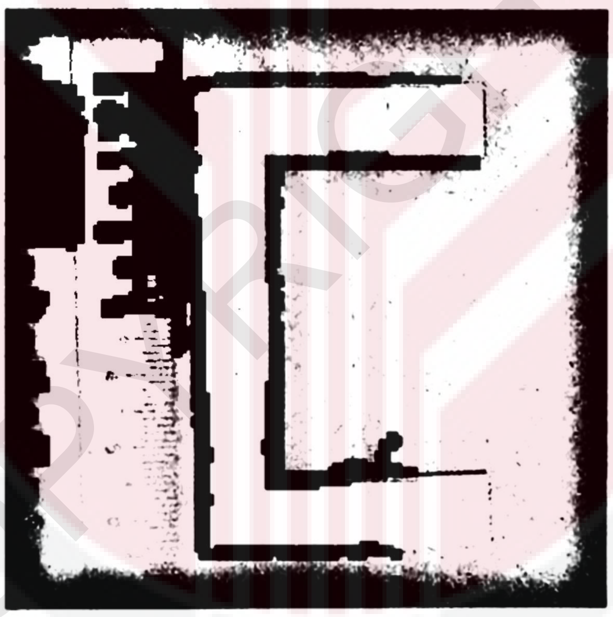


Figure 3.11: Dumbbell-shaped test specimens

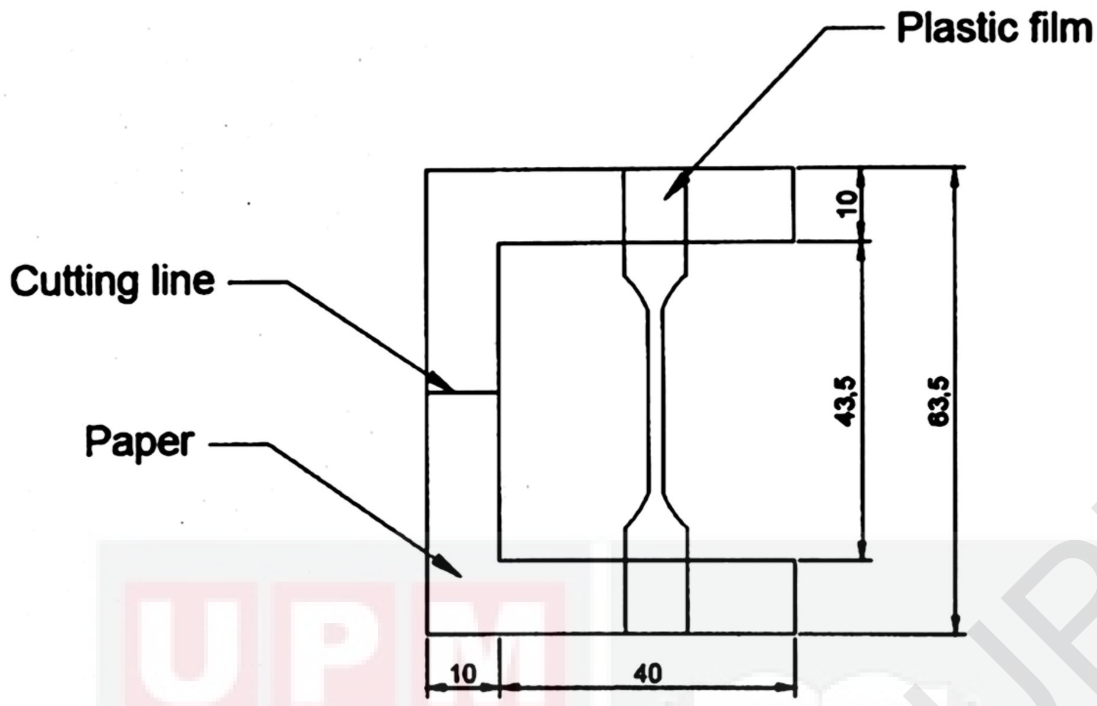


Figure 3.12: Size of tensile specimen (unit in mm)

The experiments were carried out at room temperature of 23°C ± 2°C. The width and thickness of the specimens were measured using a Vanier Calliper at several points along the gage sections of the specimens. The gage section is to ensure highest stresses occurred within the gage, and not near the grips of the texture analyzer. It is also to prevent strain and fracture of the specimen near the grips.

The specimens were glued to the C- shape paper to fix its position and then placed in the grips of the texture analyzer firmly. It was pulled to elongate at a rate of 0.4mm/s. When starting running the test, the cutting line is cut with a scissor. The samples were tested in triplicate to calculate the mean value.

3.4.2 Uniaxial tensile test on LEGO tensile tester

Similar test procedure is conducted with the tensile tester. Blue tack is attached at both ends of the specimen. The specimen is rolled and clamped on both grips. To enhance stability of the test, blue tack is fixed at the end of the grips to prevent rotation and slip condition of LEGO component during the test. It was pulled to elongate at a rate of 0.4mm/s. The samples were tested in triplicate to calculate the mean value.

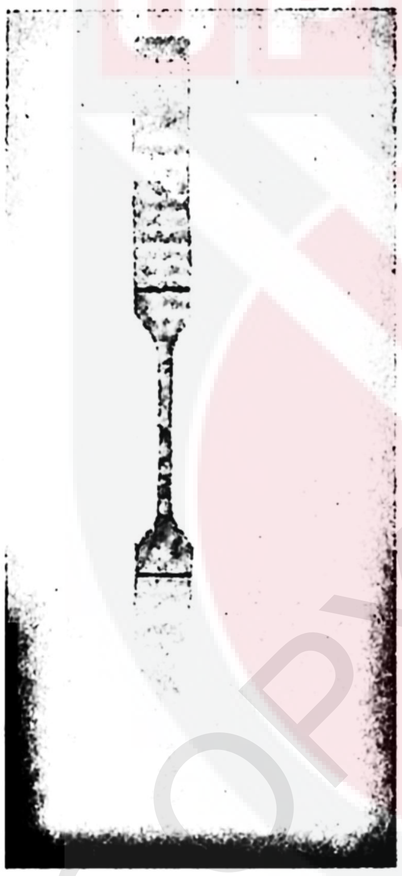


Figure 3.13: Experimental plastic specimen

Figure 3.14: Specimen with blue tack

Figure 3.15: Setup of specimen on LEGO tensile tester

3.4.3 Tensile cyclic test

This test was carried out by using the tensile tester at room temperature and the set up as shown in Figure 3.10. Two cyclic tensile tests were performed on a plastic film specimen according to the following steps:

(1) the sample was loaded for 5 second and at a strain rate of 0.4 mm/s;

(2) the sample was then unloaded for a resting period;

(3) then, the sample was loaded for 1 time.

The samples were tested in triplicate. The data is recorded and a graph is plotted.

3.4.4 Stress relaxation test

A stress-relaxation test was performed on 3 plastic specimens. Each specimen was stretched up to 5 seconds then was kept in the strained condition for 8 second. The samples were tested in triplicate. The data are recorded, and a graph is plotted.

CHAPTER 4

RESULTS AND DISCUSSION

Based on the objectives of this research, a measurement device made up of LEGO Mindstorm was developed. The design of the actual build-up of the tensile tester and comparison of the result on tensile properties of polymer with texture analyzer was explained and discussed in this chapter.

4.1 Tensile properties of polymer

In this section, comparison of the tensile strength of plastic polymer was carried out by using a texture analyzer and tensile tester respectively. The data collected from the tensile test were plotted on a graph. The graph showed the engineering stress versus the engineering strain. Figure 4.1 showed the tensile test result of the plastic film samples with thickness of 0.01mm from texture analyzer.

It is observed that the stress increases in an approximately linear manner as the applied strain increases before necking starts. (Xu et al., 2016) indicated that the engineering stress- strain curve of polymer consists of four distinct regions namely elastic region, initial necking region, cold drawing region and strain hardening to fracture region. It is noticeable that the test result possesses the characteristics mentioned by the author D.Symposium.

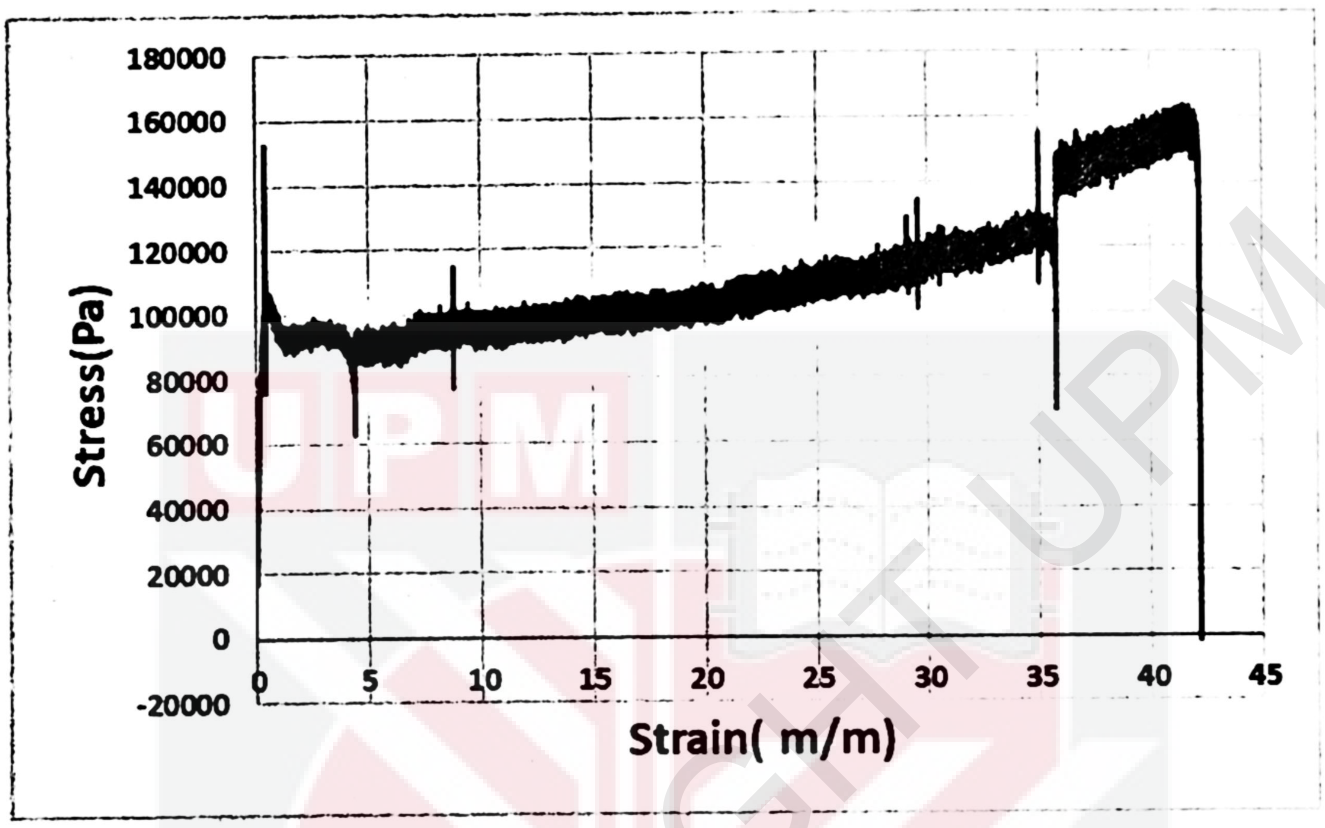


Figure 4.1: The engineering stress versus engineering strain for plastic specimen obtained from texture analyzer with 30 kg load cell capacity

Figure 4.2: Test status of plastic specimen during uniaxial tensile strength test

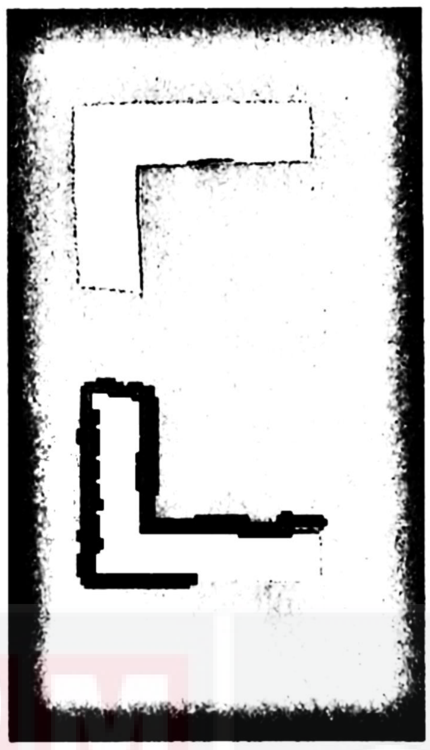


Figure 4.3: Image of fracture of plastic specimen after uniaxial tensile strength test

From the experimental graph, the curve was noisy and fluctuated that it represented the texture analyzer is not sensitive enough to detect an accurate point in the time interval. This may be due to data acquisition of 200 in calibration that captures very quickly and result in excessive data points that lead to unwanted and rough presentation of plot. To validate the graph, obtain from the LEGO measurement device, it is compared with the result from texture analyzer. Both graphs showed some similarities which according to the typical graphs that mentioned in chapter 2. Figure 4.4 presents a smoother curve compared to Figure 4.1. The data obtained from LEGO is presentable and the plot can be seen clearly despite a minor roughness in the curve. The roughness of the data is due to the function of the actuator that give the circular motion which is not enough stability. Figure 4.6 illustrated the comparison of the test results from both texture analyzer and LEGO tensile tester. The texture analyzer was able to stretch the plastic specimen to the fracture point at 40m/m of strain, but the LEGO tensile tester reached its maximum elongation of stretching at 0.6m/m of strain resulting in an unbroken plastic film as shown in figure 4.6. This is due to the limitation of the actuator that unable to stretch beyond its maximum elongation approximately 6cm.

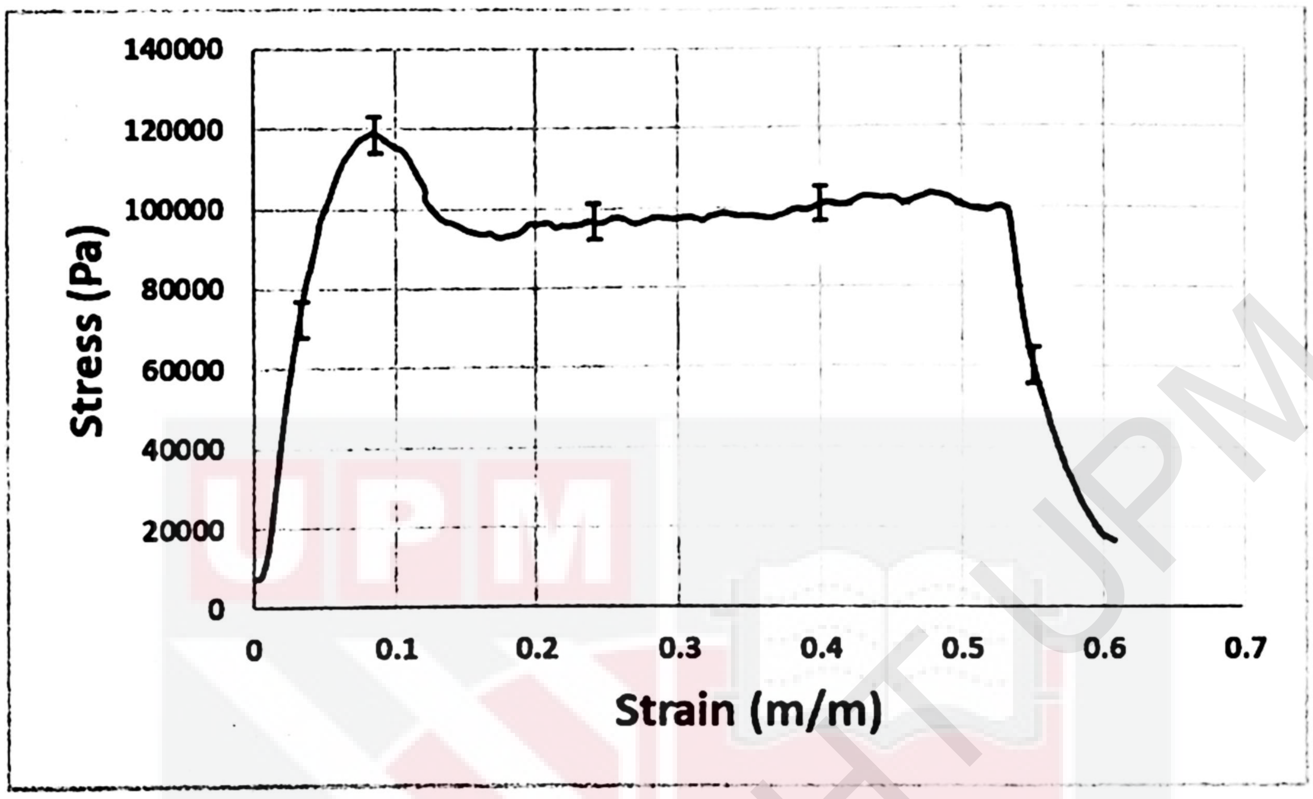


Figure 4.4: The engineering stress versus engineering strain for plastic specimen obtained from LEGO tensile tester with 2 kg load cell capacity

Figure 4.5: Stretching of plastic specimen during uniaxial tensile strength test

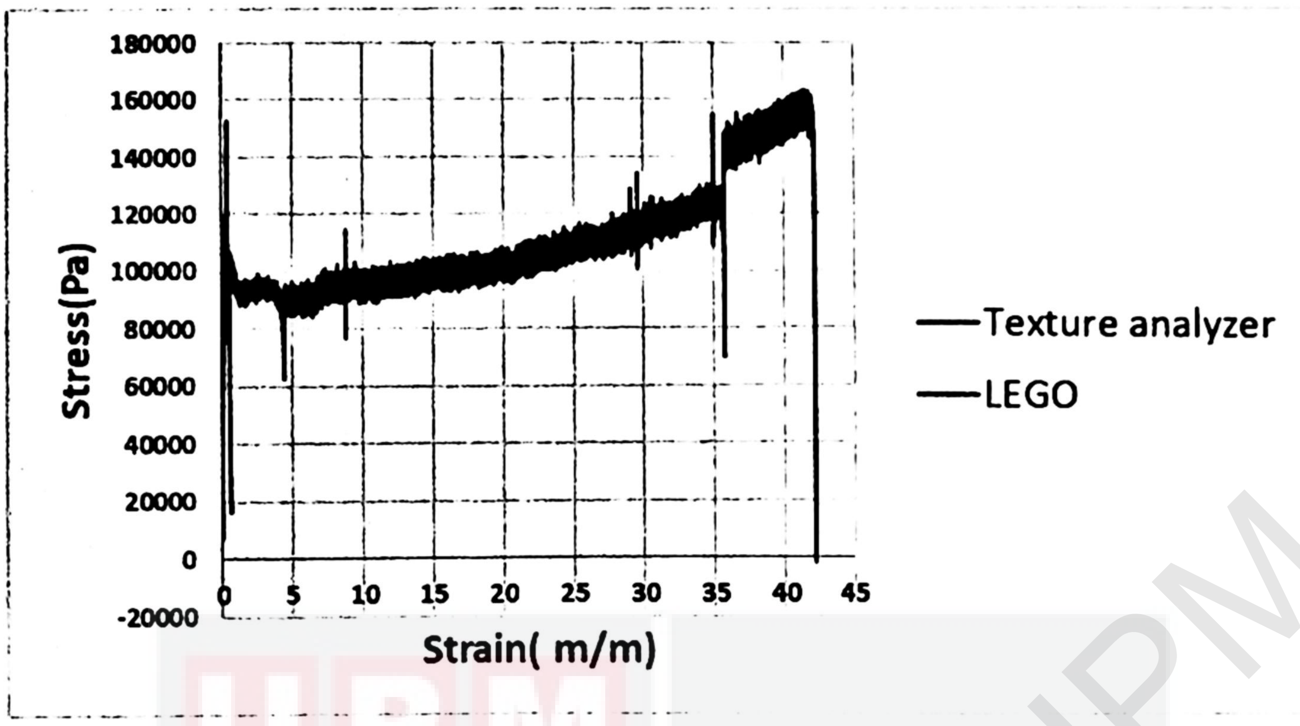


Figure 4.6: Comparison of stress- strain graph between texture analyzer and LEGO tensile tester

4.2 Tensile cyclic loading of polymer

To study the cycling load effects on the tension fracture behavior of the polymers, a tension loading cycle (2 cycles) is applied to the same specimens during tensile loading. The specimens are first loaded with a crosshead speed of 0.4 mm/s for 5 second, and then tension loading cycles are applied. In each loading cycle, the specimens are unloaded and then reloaded with same crosshead speed. As an illustration of the loading policy, a loading curve with 2 loading cycles is shown in Figure 4.6.

It can be seen that specimen behave uniform cyclic deformation as it has a shape memory effect. (Kim, Lee, & Xu, 1996). Based on figure 4.6 , it implied that the volume of specimen increases during necking process and decreases gradually when load is removed (Fang et al., 2008). This test allowed an evaluation of the deformation response of a film structure to externally applied loads or constraints. The film material can withstand forces of about 0.025kg when it is stretched. Thus, determination of plastic path length can be done for future analysis. It is a measure of the accumulated plastic strain that obtained by summing the plastic strain contribution for each cycle. This parameter is useful in correlating both deformation and failure of plastic film (Hales, Holdsworth, O'Donnell, Perrin, & Skelton, 2002).

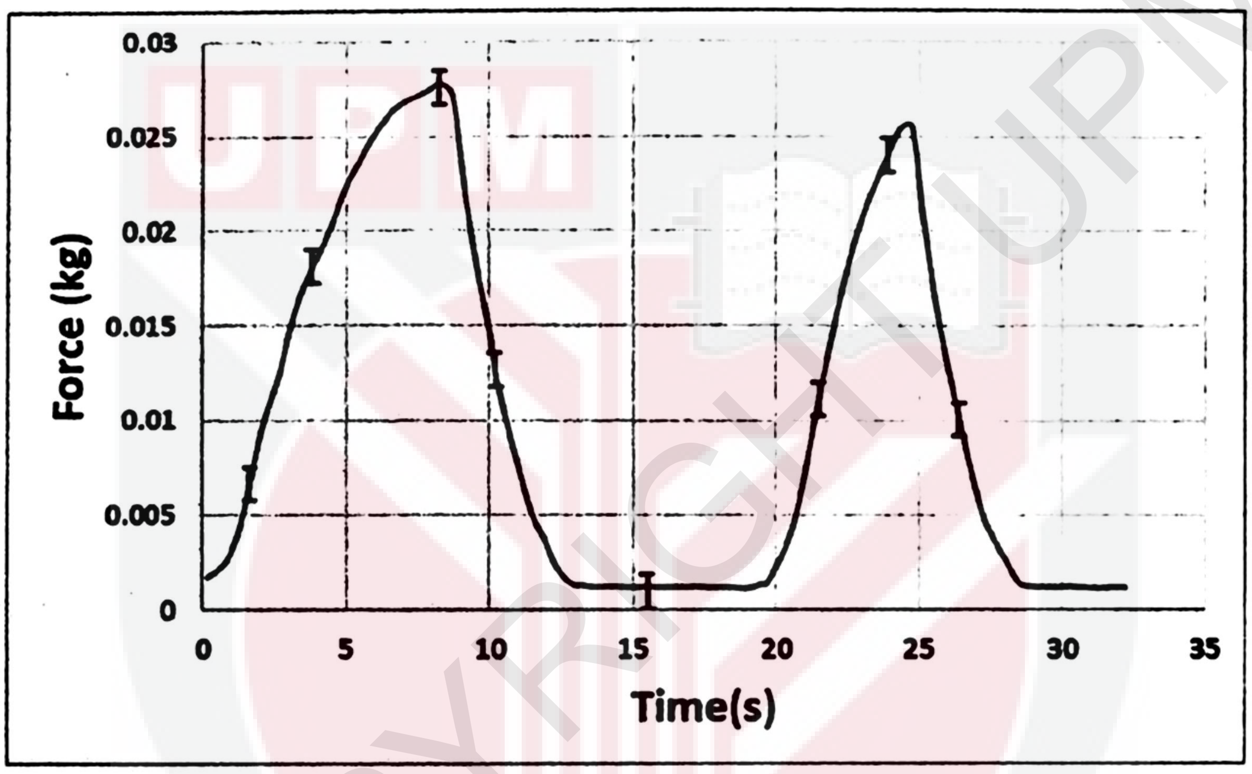


Figure 4.7: Behavior of polymer under tensile cyclic test

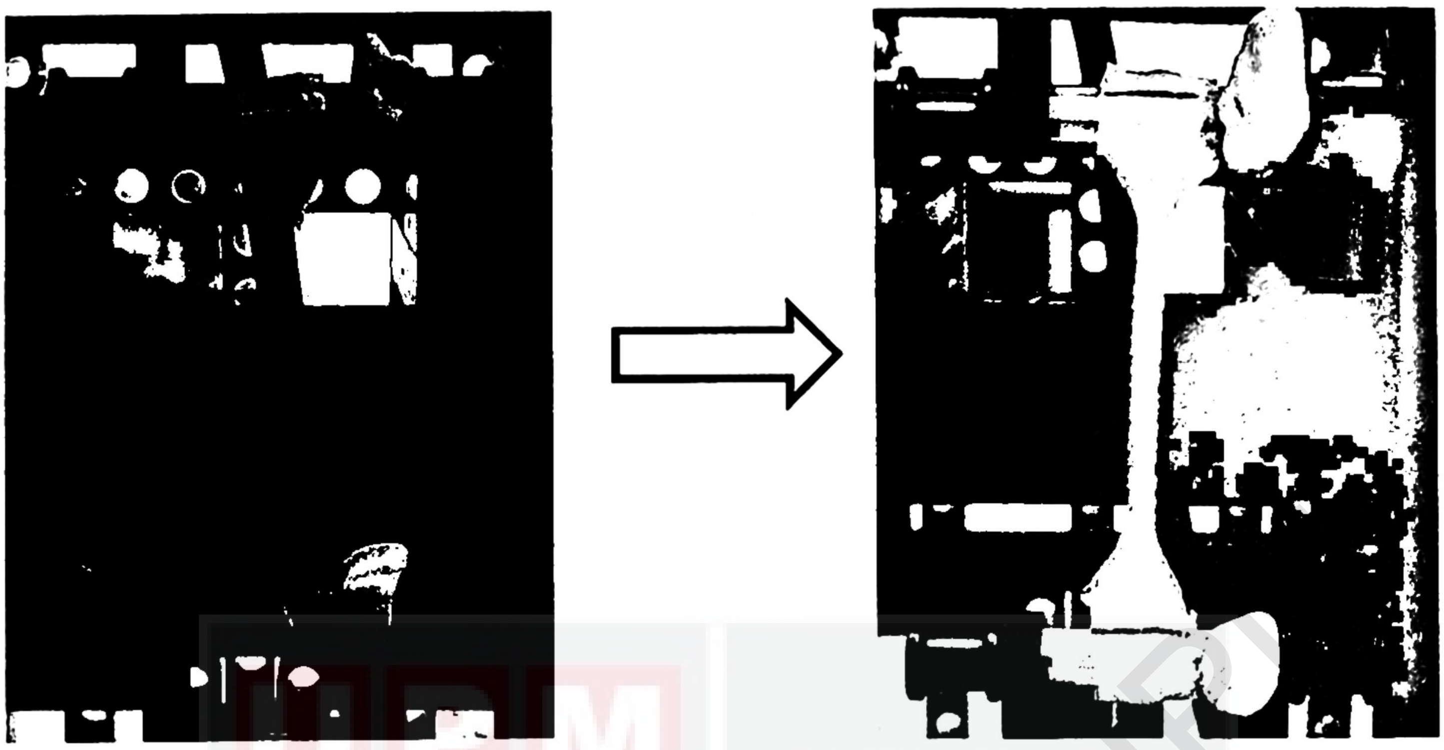


Figure 4.8 : Test status before and after using LEGO tensile tester

4.3 Stress relaxation of polymer

The force is applied to the specimen for the first 5 seconds and hold for around 10 seconds. It is observed that the force applied is increasing proportionally for the first 8 seconds and the maximum force is achieved at approximate 0.025kg. The force decay with time after 8 seconds due to stress relaxation. According to the study of (Brush Wellman Inc, 2010) , the amount of stress remaining after maximum stress will decrease with time. In addition, the graph shown a spontaneous increase of stress recovery length of the film material due to the propagation of interfacial debonding at constant strain rate (Miyake, 2010). This property is very important in load bearing applications where there is the potential for stress relaxation, or where the film material is exposed to any sort of dynamic loading, and hence it is important to be able to predict viscoelasticity of film material. The viscoelasticity can also influence fatigue behavior, and the temperature dependence of various mechanical properties, including creep resistance (Obaid, Kortschot, & Sain, 2017).

In the stress relaxation test, it is observed that the deflected contact of the specimen was unable to return to its original position. Deformation is more severe at higher stress level. Furthermore, the trend of the graph implied that the plastic specimen behaves viscoelastic characteristic as it decreases in stress with time (Singh, Rockall, Martin, Chung, & Lookhart, 2006). The tensile tester model is moderately trustworthy and reliable in obtaining the mechanical result. Furthermore, the result proved that the tensile tester is suitable to use for this test as it is capable of measuring very small elongation accurately as pointed out by (Shah Vishu, 2007)

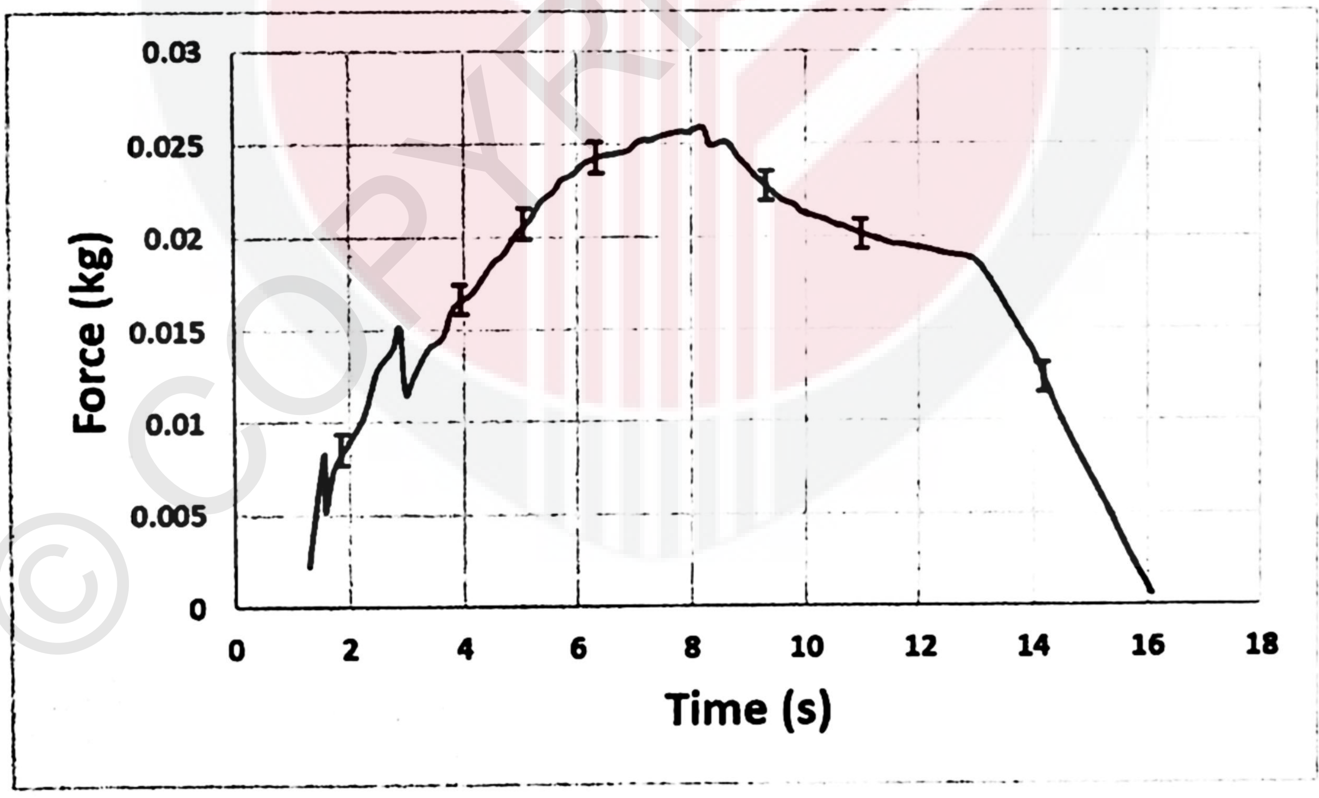


Figure 4.9: Stress relaxation curve plastic specimen

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this research is to build a measurement device tensile tester that used for mechanical testing of plastic film. The overall design of the tensile tester is completed and available for conducting mechanical testing on plastic film. The open-source tensile tester presented in this work offers a simple and cost-effective approach to scientific measurements by using LEGO Mindstorms and "smart-sensors". The research work of Richard Moser is used as a reference when designing and assembling tensile tester in this project.

In this study, investigation on the result obtained from uniaxial tensile test had been done to compare the result from texture analyzer. Results showed that the stress-strain engineering curve obtained from texture analyzer presented a waxy and fluctuated trend. This means that the equipment is unable to detect an accurate tensile data in the time interval of the experiment due to its data acquisition application. While the transportable LEGO tensile tester showed the capability in providing reproducible and presentable results in engineering studies. Realization in LEGO of machinery such as motor, controller and actuator demonstrates its potential for sophisticated and reliable measurements.

Besides, behavior of plastic film was studied by performing tensile cyclic and stress relaxation test respectively. The specimen behaves uniform cyclic deformation due to its shape memory effect. Result shown that the plastic specimen is a viscoelastic polymer.

5.2 Recommendations

In future research, a study and an improvement of the LEGO motor can be carried out to investigate the effect of its mechanic to the result of mechanical test in order to obtain a smoother curve on the stress-strain graph. Additionally, limitation of the actuator results in unbroken of the plastic specimen. It is suggested to choose an actuator that can be stretched more than 20cm to allow proper mechanical testing of material. Hence, further comprehensive study about the buildup of tensile tester should be done to ensure fabrication of an established laboratory equipment.

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APPENDICES

Appendix A: MATLAB coding for grip m file

```
%% Clear Variables and Open FUTEK USB DLL Assembly

clear variables;
pause('on');

%Net.addAssdownembly requires the full file path to access
private .dll files
%such as the FUTEK USB DLL.
%With the current folder set as where both this script and
the .dll file
%are located, the which() function returns the full file
path.

%The included copy of FUTEK_USB_DLL.dll has been compiled
for either 32 bit
%or 64 bit platforms. If you are running MATLAB 32 bit use
only the 32 bit
%.dll file and if you are using MATLAB 64 bit use only the
64 bit .dll
%file.

%Full .dll file API available here:
http://www.futek.com/files/docs/API/FUTEK_USB_DLL/webframe.
html

%Requires .Net 4.0 and Windows
NET.addAssembly(which('FUTEK_USB_DLL.dll'));
import FUTEK_USB_DLL.*
import FUTEK_USB_DLL.USB_DLL.*

%Serial Number in ' ' for your Instrument or USB Output Kit
serialNumber = '492848';

%% Initialize Variables

instr = USB_DLL();
%============USER INPUT==========================%
processType = input('Please enter the type of test to \n
proceed(down, up, tensile, relaxation, cyclic)\n','s');
```

```
if strcmpi('tensile',processType)

%input------------------------------------------------%
        motorRate = input('insert motor power(%)(0-100)\n');
        samples = 1000; %input('insert number of sample\n');
        datainterval = input ('time interval of data
point\n');
        RUNTIME = input('insert runtime\n');
        threshold = input('set threshold value(kg):\n');
%------------------------------------------------------------
--%

elseif strcmpi('relaxation',processType)
%input-------------------------------------------------------
--%
        motorRate = input('insert motor power(%)(0-100)\n');
        samples = 1000; %input('insert number of sample\n');
        datainterval = input ('time interval of data
point\n');
        RUNTIME = input('insert runtime\n');
        RELAXTIME = input('Time taken for relaxation\n');
        threshold = input('set threshold value(kg):\n');
%------------------------------------------------------------
--%

elseif strcmpi('cyclic',processType)
%input-------------------------------------------------------
--%
        motorRate = input('insert motor power(%)(0-100)\n');
        samples = 1000; %input('insert number of sample\n');
        datainterval = input ('time interval of data
point\n');
        RUNTIME = input('insert runtime\n');
        cycle = input('number of cycle\n');
        threshold = input('set threshold value(kg):\n');

%------------------------------------------------------------
--%


else
    disp('invalid input')
end
%============================================================
==%
deviceHandle = '';
```

```
deviceStatus = 0;
deviceStatusChr = '';
temp = 0;
offsetValue = 0;
fullScaleValue = 0;
fullScaleLoad = 0;
decimalPoint = 0;
normalData = 0;
calculatedReading = 0;
unitCode = 0;
unitChr = '';
unitCodeData = {'atm'; 'bar'; 'dyn'; 'ft-H20'; 'ft-lb'; 'g';
'g-cm'; 'g-mm'; 'in-H20'; 'in-lb';
    'in-oz'; 'kdyn'; 'kg'; 'kg-cm'; 'kg/cm2'; 'kg-m';
'klbs'; 'kN'; 'kPa'; 'kpsi';
    'lbs'; 'Mdyn'; 'mmHG'; 'mN-m'; 'MPa'; 'MT'; 'N'; 'N-cm';
'N-m'; 'N-mm';
    'oz'; 'psi'; 'Pa'; 'T'; 'mV/V'; 'µA'; 'mA'; 'A'; 'mm';
'cm';
    'dm'; 'm'; 'km'; 'in'; 'ft'; 'yd'; 'mi'; 'µg'; 'mg';
'LT';
    'mbar'; '?C'; '?F'; 'K'; '?Ra'; 'kN-m'; 'g-m'; 'nV';
'µV'; 'mV';
    'V'; 'kV'; 'NONE'};
calculatedTable = cell(samples,4);

%==========================LEGO
PART==========================%
%LEGO Setup
mylego = legoev3('usb'); %connect ev3 via usb
mymotor = motor(mylego,'A'); %Large motor
mytouch1 = touchSensor(mylego,1); % 'killswitch' sensor at
the bottom part
mytouch3 = touchSensor(mylego,3); % 'killswitch' sensor at
the top part

%===========================================================
==%


%% Open Connection and Begin Data Capture Run
%Intializes the connection to instrument with the specified
Serial Number.
%Fetches Device Status to determine if connection is
successful or returns
%the error code and exits
instr.Open_Device_Connection(serialNumber);
```

```
deviceStatus = instr.DeviceStatus();
if deviceStatus == 0
    disp('Pass')
else
    deviceStatusChr = num2str(deviceStatus);
    disp(['Device Error  \n disconnect Futek usb \n'
deviceStatusChr])
    return;
end

%Fetches the device handle needed to retrieve stored values
used in load
%calculation
deviceHandle = instr.DeviceHandle();

%--------------------- Set motor speed -------------------
--%
mymotor.Speed = motorRate;
start(mymotor)

a=figure;
grid on
tic

%Begin loop to collect samples

%UNIAXIAL TENSILE TEST--------------------------------------
--%

if strcmpi('tensile',processType) %UNIAXIAL TENSILE TEST

    tensile

savefig(a,'tensile.fig')
f = openfig('tensile.fig');
L = findobj(f, 'type', 'line');
x_data = get(L, 'xdata');
y_data = get(L, 'ydata');

%----------------------------------------------------------
--%

%%RELAXATION TEST-------------------------------------------
--%
elseif strcmpi('relaxation',processType) %RELAXATION TEST

    relaxationtensile
```

```
savefig(a,'relaxation.fig')
f = openfig('relaxation.fig');
L = findobj(f, 'type', 'line');
x_data = get(L, 'xdata');
y_data = get(L, 'ydata');


%-----------------------------------------------------------
--%
%CYCLIC COMPRESSION TEST------------------------------------
--%
elseif strcmpi('cyclic',processType) %CYCLIC COMPRESSION
TEST

    for i=1:cycle
   tensile
    end

savefig(a,'cyclic_compression.fig')
f = openfig('cyclic_compression.fig');
L = findobj(f, 'type', 'line');
x_data = get(L, 'xdata');
y_data = get(L, 'ydata');


%-----------------------------------------------------------
--%
%PLATE MOVES DOWN------------------------------------------
--%
elseif strcmpi('down',processType)

    down

%-----------------------------------------------------------
--%
%PLATE MOVES UP--------------------------------------------
--%
else strcmpi('up',processType)

    up

%-----------------------------------------------------------
--%
end

%% Close Connection
```

```
% Close the connection to properly disconnect device and
allow access by
% other programs, otherwise you must disconnect drive from
USB port.
instr.Close_Device_Connection(deviceHandle);
```

Appendix B : MATLAB coding for tensile m file

```
timerID = tic;  %# Start a clock and return the timer ID
for x1=samples %return original position
    %% Capture Variables

    %Uses the FUTEK USB DLL to retrieve values for load
calculation
    %The .dll returns these values as a System.String
    %This is then converted to a char value and then a
number
    %Lastly if there was a retrieval error the .dll returns
'Error' which
    %converts to an empty value. isEmpty() test for that
and continues
    %retrieval until a number is returned.

mymotor.Speed = -motorRate; %return original position
start(mymotor)

while (toc(timerID) <=RUNTIME)


    %StopBySensor
    sensor2 = readTouch(mytouch3);
    if (sensor2 == 1)

        stop(mymotor,1)
    break
    end
    % Offset Value
    while true
        temp =
str2num(char(instr.Get_Offset_Value(deviceHandle))); %#ok<*
ST2NM>
        if ~(isempty(temp))
            break
        end
    end
    offsetValue = temp;

    %Full Scale Value
    while true
        temp =
str2num(char(instr.Get_Fullscale_Value(deviceHandle)));
        if ~(isempty(temp))
            break
```

```
        end
    end
    fullScaleValue = temp;

    % Full Scale Load
    while true
        temp =
str2num(char(instr.Get_Fullscale_Load(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleLoad = temp;

    % Decimal Point
    while true
        temp =
str2num(char(instr.Get_Decimal_Point(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    decimalPoint = temp;
    %Test to see if decimal point returned is outside
defined decimal point
    %values
    %See here for more information:
    %http://www.futek.com/files/docs/API/FUTEK_USB_DLL/webf
rame.html#DecimalPointCodes.html
    if decimalPoint >= 6
        disp('Decimal Point Out of Range/Undefined')
        return;
    end

    % Get Unit Code and Convert to Actual Load
    while true
        temp =
str2num(char(instr.Get_Unit_Code(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    unitCode = temp + 1;
    unitChr = unitCodeData{unitCode,1};

    %Get Normal Data
    while true
```

```
        temp =
str2num(char(instr.Normal_Data_Request(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    normalData = temp;

    %% Calculate Read Out and Display

    % Use retrieved variables to calculate measured load
cell output
    calculatedReading = normalData - offsetValue;
    calculatedReading = calculatedReading/(fullScaleValue -
offsetValue);
    calculatedReading = calculatedReading*fullScaleLoad;
    calculatedReading = calculatedReading/10^decimalPoint;
    tnow = datestr(now,'dd-mm-yyyy HH:MM:SS
FFF'); %Retrieve Current Time

    dispStr = [num2str(calculatedReading), ' ', unitChr];
    disp(dispStr)

    y=-calculatedReading;

    if(y>=threshold)
    hold on
 %%ax1=axes('Nextplot','replacechildren');
    %axes(ax1);
    plot(toc,y,'or');
    xlabel('time (s)')
    ylabel('force (kg)')

    %a=samples*2+wait*100;
    %xlim([0 a])
    ylim([-0.1 0.1])


 %hold off
    end
    %Store Sample Number, Reading, Units, and Time in a
Cell Array
    calculatedTable(x1,1:4)={x1, calculatedReading, unitChr,
tnow};

    %Pause program to prevent repolling the instrument
    pause(datainterval);
```

```
end
break
end

stop(mymotor,1)

timerID=tic;

for x2=x1:x1*2
    %% Capture Variables

    %Uses the FUTEK USB DLL to retrieve values for load
calculation
    %The .dll returns these values as a System.String
    %This is then converted to a char value and then a
number
    %Lastly if there was a retrieval error the .dll returns
'Error' which
    %converts to an empty value. isEmpty() test for that
and continues
    %retrieval until a number is returned.



while (toc(timerID) <=RUNTIME)
mymotor.Speed = motorRate; %return original position
start(mymotor) %StopBySensor
    sensor1 = readTouch(mytouch1);
    if (sensor1 == 1)
        stop(mymotor,1)
        break
    end

    % Offset Value
    while true
        temp =
str2num(char(instr.Get_Offset_Value(deviceHandle))); %#ok<*
ST2NM>
        if ~(isempty(temp))
            break
        end
    end
    offsetValue = temp;

    %Full Scale Value
    while true
```

```
        temp =
str2num(char(instr.Get_Fullscale_Value(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleValue = temp;

    % Full Scale Load
    while true
        temp =
str2num(char(instr.Get_Fullscale_Load(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleLoad = temp;

    % Decimal Point
    while true
        temp =
str2num(char(instr.Get_Decimal_Point(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    decimalPoint = temp;
    %Test to see if decimal point returned is outside
defined decimal point
    %values
    %See here for more information:
    %http://www.futek.com/files/docs/API/FUTEK_USB_DLL/webf
rame.html#DecimalPointCodes.html
    if decimalPoint >= 6
        disp('Decimal Point Out of Range/Undefined')
        return;
    end

    % Get Unit Code and Convert to Actual Load
    while true
        temp =
str2num(char(instr.Get_Unit_Code(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    unitCode = temp + 1;
```

```
    unitChr = unitCodeData{unitCode,1};

    %Get Normal Data
    while true
        temp =
str2num(char(instr.Normal_Data_Request(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    normalData = temp;

    %% Calculate Read Out and Display

    % Use retrieved variables to calculate measured load
cell output
    calculatedReading = normalData - offsetValue;
    calculatedReading = calculatedReading/(fullScaleValue -
offsetValue);
    calculatedReading = calculatedReading*fullScaleLoad;
    calculatedReading = calculatedReading/10^decimalPoint;
    tnow = datestr(now,'dd-mm-yyyy HH:MM:SS
FFF'); %Retrieve Current Time

    dispStr = [num2str(calculatedReading), ' ', unitChr];
    disp(dispStr)


    y=-calculatedReading;
    if(y>=threshold)
    hold on
    %%ax1=axes('Nextplot','replacechildren');
    %axes(ax1);
    plot(toc,y,'*r');
%     a=samples*2
%     xlim([0 a])
%     ylim([0 0.5])
    hold off
    end
    %Store Sample Number, Reading, Units, and Time in a
Cell Array
    calculatedTable(x2,1:4)={x2, calculatedReading, unitChr,
tnow};

    %Pause program to prevent repolling the instrument
    pause(datainterval);
end
```

```
break
end


stop(mymotor,1)
```

Appendix C : MATLAB coding for relaxationtensile m. file

```
timerID = tic;  %# Start a clock and return the timer ID

    for x1=1:samples
    %% Capture Variables

    %Uses the FUTEK USB DLL to retrieve values for load
calculation
    %The .dll returns these values as a System.String
    %This is then converted to a char value and then a
number
    %Lastly if there was a retrieval error the .dll returns
'Error' which
    %converts to an empty value. isEmpty() test for that
and continues
    %retrieval until a number is returned.


mymotor.Speed = -motorRate; %return original position
start(mymotor)

while (toc(timerID) <=RUNTIME)


    %StopBySensor
    sensor2 = readTouch(mytouch3);
    if (sensor2 == 1)

        stop(mymotor,1)
    break
    end
    % Offset Value
    while true
        temp =
str2num(char(instr.Get_Offset_Value(deviceHandle))); %#ok<*
ST2NM>
        if ~(isempty(temp))
            break
        end
    end
    offsetValue = temp;

    %Full Scale Value
    while true
        temp =
str2num(char(instr.Get_Fullscale_Value(deviceHandle)));
```

```
        if ~(isempty(temp))
            break
        end
    end
    fullScaleValue = temp;

    % Full Scale Load
    while true
        temp =
str2num(char(instr.Get_Fullscale_Load(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleLoad = temp;

    % Decimal Point
    while true
        temp =
str2num(char(instr.Get_Decimal_Point(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    decimalPoint = temp;
    %Test to see if decimal point returned is outside
defined decimal point
    %values
    %See here for more information:
    %http://www.futek.com/files/docs/API/FUTEK_USB_DLL/webf
rame.html#DecimalPointCodes.html
    if decimalPoint >= 6
        disp('Decimal Point Out of Range/Undefined')
        return;
    end

    % Get Unit Code and Convert to Actual Load
    while true
        temp =
str2num(char(instr.Get_Unit_Code(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    unitCode = temp + 1;
    unitChr = unitCodeData{unitCode,1};
```

```
    %Get Normal Data
    while true
        temp =
str2num(char(instr.Normal_Data_Request(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    normalData = temp;

    %% Calculate Read Out and Display

    % Use retrieved variables to calculate measured load
cell output
    calculatedReading = normalData - offsetValue;
    calculatedReading = calculatedReading/(fullScaleValue -
offsetValue);
    calculatedReading = calculatedReading*fullScaleLoad;
    calculatedReading = calculatedReading/10^decimalPoint;
    tnow = datestr(now,'dd-mm-yyyy HH:MM:SS
FFF'); %Retrieve Current Time

    dispStr = [num2str(calculatedReading), ' ', unitChr];
    disp(dispStr)

    y=-calculatedReading;

    if(y>=threshold)
    hold on
 %%ax1=axes('Nextplot','replacechildren');
    %axes(ax1);
    plot(toc,y,'or');
    xlabel('time (s)')
    ylabel('force (kg)')

    %a=samples*2+wait*100;
    %xlim([0 a])
    ylim([-0.1 0.1])


 %hold off
    end
    %Store Sample Number, Reading, Units, and Time in a
Cell Array
    calculatedTable(x1,1:4)={x1, calculatedReading, unitChr,
tnow};
```

```
    %Pause program to prevent repolling the instrument
    pause(datainterval);

end
break
end
    stop(mymotor,1)


    timerID = tic;  %# Start a clock and return the timer
ID
        for x2=x1:x1*2 %Relaxation
    %% Capture Variables

    %Uses the FUTEK USB DLL to retrieve values for load
calculation
    %The .dll returns these values as a System.String
    %This is then converted to a char value and then a
number
    %Lastly if there was a retrieval error the .dll returns
'Error' which
    %converts to an empty value. isEmpty() test for that
and continues
    %retrieval until a number is returned.

while (toc(timerID) <=RELAXTIME)
     %StopBySensor
    sensor2 = readTouch(mytouch3);
    if (sensor2 == 1)
        mymotor.Speed = motorRate;
        stop(mymotor,1)
        break
    end

    % Offset Value
    while true
        temp =
str2num(char(instr.Get_Offset_Value(deviceHandle))); %#ok<*
ST2NM>
        if ~(isempty(temp))
            break
        end
    end
    offsetValue = temp;

    %Full Scale Value
    while true
```

```
        temp =
str2num(char(instr.Get_Fullscale_Value(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleValue = temp;

    % Full Scale Load
    while true
        temp =
str2num(char(instr.Get_Fullscale_Load(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleLoad = temp;

    % Decimal Point
    while true
        temp =
str2num(char(instr.Get_Decimal_Point(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    decimalPoint = temp;
    %Test to see if decimal point returned is outside
defined decimal point
    %values
    %See here for more information:
    %http://www.futek.com/files/docs/API/FUTEK_USB_DLL/webf
rame.html#DecimalPointCodes.html
    if decimalPoint >= 6
        disp('Decimal Point Out of Range/Undefined')
        return;
    end

    % Get Unit Code and Convert to Actual Load
    while true
        temp =
str2num(char(instr.Get_Unit_Code(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    unitCode = temp + 1;
```

```
    unitChr = unitCodeData{unitCode,1};

    %Get Normal Data
    while true
        temp =
str2num(char(instr.Normal_Data_Request(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    normalData = temp;

    %% Calculate Read Out and Display

    % Use retrieved variables to calculate measured load
cell output
    calculatedReading = normalData - offsetValue;
    calculatedReading = calculatedReading/(fullScaleValue -
offsetValue);
    calculatedReading = calculatedReading*fullScaleLoad;
    calculatedReading = calculatedReading/10^decimalPoint;
    tnow = datestr(now,'dd-mm-yyyy HH:MM:SS
FFF'); %Retrieve Current Time

    dispStr = [num2str(calculatedReading), ' ', unitChr];
    disp(dispStr)


    y=-calculatedReading;
    if(y>=threshold)
    hold on
    %%ax1=axes('Nextplot','replacechildren');
    %axes(ax1);
    plot(toc,y,'*r');
%     a=samples*2
%     xlim([0 a])
%     ylim([0 0.5])
    hold off
    end
    %Store Sample Number, Reading, Units, and Time in a
Cell Array
    calculatedTable(x2,1:4)={x2, calculatedReading, unitChr,
tnow};

    %Pause program to prevent repolling the instrument
    pause(datainterval);
end
```

```
break
end


stop(mymotor,1)

  timerID = tic;  %# Start a clock and return the timer ID
    for x3=x2:x2*2 %return original position
    %% Capture Variables

    %Uses the FUTEK USB DLL to retrieve values for load
calculation
    %The .dll returns these values as a System.String
    %This is then converted to a char value and then a
number
    %Lastly if there was a retrieval error the .dll returns
'Error' which
    %converts to an empty value. isEmpty() test for that
and continues
    %retrieval until a number is returned.


while (toc(timerID) <=RUNTIME)
mymotor.Speed = motorRate; %return original position
start(mymotor) %StopBySensor
    sensor1 = readTouch(mytouch1);
    if (sensor1 == 1)
        stop(mymotor,1)
        break
    end

    % Offset Value
    while true
        temp =
str2num(char(instr.Get_Offset_Value(deviceHandle))); %#ok<*
ST2NM>
        if ~(isempty(temp))
            break
        end
    end
    offsetValue = temp;

    %Full Scale Value
    while true
        temp =
str2num(char(instr.Get_Fullscale_Value(deviceHandle)));
        if ~(isempty(temp))
```

```
            break
        end
    end
    fullScaleValue = temp;

    % Full Scale Load
    while true
        temp =
str2num(char(instr.Get_Fullscale_Load(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    fullScaleLoad = temp;

    % Decimal Point
    while true
        temp =
str2num(char(instr.Get_Decimal_Point(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    decimalPoint = temp;
    %Test to see if decimal point returned is outside
defined decimal point
    %values
    %See here for more information:
    %http://www.futek.com/files/docs/API/FUTEK_USB_DLL/webf
rame.html#DecimalPointCodes.html
    if decimalPoint >= 6
        disp('Decimal Point Out of Range/Undefined')
        return;
    end

    % Get Unit Code and Convert to Actual Load
    while true
        temp =
str2num(char(instr.Get_Unit_Code(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    unitCode = temp + 1;
    unitChr = unitCodeData{unitCode,1};

    %Get Normal Data
```

```
    while true
        temp =
str2num(char(instr.Normal_Data_Request(deviceHandle)));
        if ~(isempty(temp))
            break
        end
    end
    normalData = temp;

    %% Calculate Read Out and Display
    % Use retrieved variables to calculate measured load
cell output
    calculatedReading = normalData - offsetValue;
    calculatedReading = calculatedReading/(fullScaleValue -
offsetValue);
    calculatedReading = calculatedReading*fullScaleLoad;
    calculatedReading = calculatedReading/10^decimalPoint;
    tnow = datestr(now,'dd-mm-yyyy HH:MM:SS
FFF'); %Retrieve Current Time

    dispStr = [num2str(calculatedReading), ' ', unitChr];
    disp(dispStr)


    y=-calculatedReading;
    if(y>=threshold)
    hold on
    %%ax1=axes('Nextplot','replacechildren');
    %axes(ax1);
    plot(toc,y,'*r');
%     a=samples*2
%     xlim([0 a])
%     ylim([0 0.5])
    hold off
    end
    %Store Sample Number, Reading, Units, and Time in a
Cell Array
    calculatedTable(x3,1:4)={x3, calculatedReading, unitChr,
tnow};

    %Pause program to prevent repolling the instrument
    pause(datainterval);
end
break
end

stop(mymotor,1)
```