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Detecting Force Damaging Limits for Polymer Materials Using Strain Gauge Sensor

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Abstract

Mechanical properties of polymer materials and its characteristics are needed to determine applied force limitations on flexible objects. Determining force limits for polymers is very difficult due to its high flexibility. This paper presents an experimental procedure to overcome the difficulties mentioned above. The experimental procedure is done on three selected flexible objects (High Density Polyethylene, Phenol-Formaldehyde, and Natural Rubber) at 20 ^{o}C to find the stress point for the objects without damage. The procedure depends on the mechanical properties of polymers and uses strain gauge force sensors (1 N to 20 N) equipped on steel rod to measure the force and strain of selected objects. The results present the accuracy and efficiency of the procedure based on the applied forces and the deformity of objects which depend on the pressure of steel rode.

Keywords: Polymers; strain gauge; stress; flexibility.

1. Introduction

Mechanical properties of polymer materials and its characteristics are quite different from on object to another. Factories of polymer materials uses robots to grab the objects which provide temporary contact with the object to be grasped. Since there are many types of workspace with different shapes and sizes to be handled, so it is impossible to design a universal gripper suitable for all polymers. This leads to the importance of determining applied force limitations on flexible objects by robots. Grippers of robots vary based on the task that they designed for. The grippers used in industry re-manufactured for a single task and they can only handle the objects which have similar properties like geometry, weight etc.

Robots are provided with sensors measure a physical properties of the objects in the environment and transform it into a signal which can be recognized and analyzed by the robot control [1]. Force sensors are used to measure the interaction force between grippers and the part to be handled .In some instances, researchers in robotics take leads from the study of human grip force dynamics. In [2, 3] the authors describe a control strategy for robot hands based on the human precision grip dynamics. In [4] the author gave an overview of the grasp geometry, path planning, fine motion control, grasping, finger and hand control, and tactile sensing ending with new robotic hand design. A fully integrated force/tactile sensor has been developed in [5], as well as a technique to compute the pressure centroid and the associated ellipsoid during contact in [6]. A dynamical model for viscoelastic pads useful to quantitatively characterize the behaviour of materials used to cover robotic hands was presented in [7] as well as a control approach, exploiting the relation between the stiffness and the applied load, was proposed in [8] in order to arbitrarily change the overall stiffness of a robot hand. Many publications present the use of strain gauge force sensors and measurement procedures such as in [9-14].

This paper presents a procedure depends on the mechanical properties of polymers and uses strain gauge force sensors (1 N to 20 N) equipped on steel rod to measure the force and strain of selected ob-

jects, where the steel rod simulates the robot hand.

2. Force, Stress/Strain, Measurement

The force exerted on object being gripped by the robot gripper should be monitored in order to avoid excessive force and also to apply sufficient force so that the component does not slip. The force sensor provides the quantity of force being applied on the object and stops the gripper motor instantly. Most of the objects in the real world are not rigid solids. Polymer materials for example, need very low force to be gripped. The maximum force was selected to be approximately 20 N, so our force measurement was performed below 20 N. Furthermore a robot is able to distinguish visually similar objects that have different elasticity properties by using only the information obtained from the force sensor.

2.1. Force sensing and strain analysis

One of the simplest methods of sensing a force (or pressure) exerted on an object is to detect the deflection of the robotic gripper in response to such an applied force. Strain gauges can be used to produce a robotic force sensing element. The strain gauge provides a convenient and accurate means of doing this. The principle underlying the operation of a strain gauge is that a mechanical deformation produces a change in resistance of the gauge, which can then be related to the applied force. We carried out some experimental procedures of force measurement by using a strain gauge separately and on a steel rod (jaw of gripper). Figure 2.1 represents the circuit used for testing and measuring.

It is important to analyze the sensors before it is used in any application. Here the strain gauge is pasted on a steel rod (jaw of gripper) pair on top surface and pair on lower surface the deflection on the steel rod causes change in resistance in the gauge which proportional to the force applied on the rod. Hence it becomes important to study behaviour of the base metal over which the strain gauge is pasted. Analysis was used here to study the behaviour of the metal used. Different forces were given as inputs and the stress and strain on the metal were studied. This helps in determining the maximum force which could be given to the steel rod. This also helps in determining the strain in the strain gauge which can be used for calibrating the strain gauge in advance. The behaviour of the gauge can be studied for very minute force which may not be available for calibrating.

Figure 2.2 shows the strain developed on the steel rod of 2 mm thickness and 59 mm x 20 mm area for force ranging from 1 N to 20 N.

Known force (F) is applied in the end of the steel rod while the rod is fixed at one end. When a load (F) is applied at the end of the rod, the tensile stress (σ) along the x-axis at the top surface is given as:

$$\sigma = \frac{F}{A} \tag{2.1}$$

As the strain gauge is placed at the end of the rod on a distance of 75 mm from the rod end. For this, strain will be measured by a strain gauge bonded to the top surface of a beam or is given by

$$\varepsilon = \frac{6FX_2}{Ebt^2} \tag{2.2}$$

If gauge factor is known, measurement of dR/R allows measurement of the strain$(dL/L) = N$. Where dR is change in resistance. Here the gauge factor of strain gauge used has a value of 2. Gauges can be applied on curved surfaces; the minimum safe radius can be as small as 0.06 inches in some gauges. Typical gauge resistances are 120, 350 and 1000 Ω, with allowable gauge current 0.0275 to 0.558 voltage. Resistance of gauge used here has 350 Ω. Maximum measurable micro strain varies from 17.9 to 355.31. It is seen that for maximum force the change in resistance is only 0.074% [15].

Strain gauge calibration is needed for accurate results. Calibration relates the sensor's electrical output to an actual engineering unit, such as pounds or Newton. This is done by applying to the sensor, and equating the output voltage to this force.

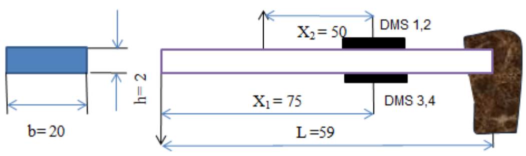

Figure 2.2: Dimensions of the gripping rod (strain on steel rod).

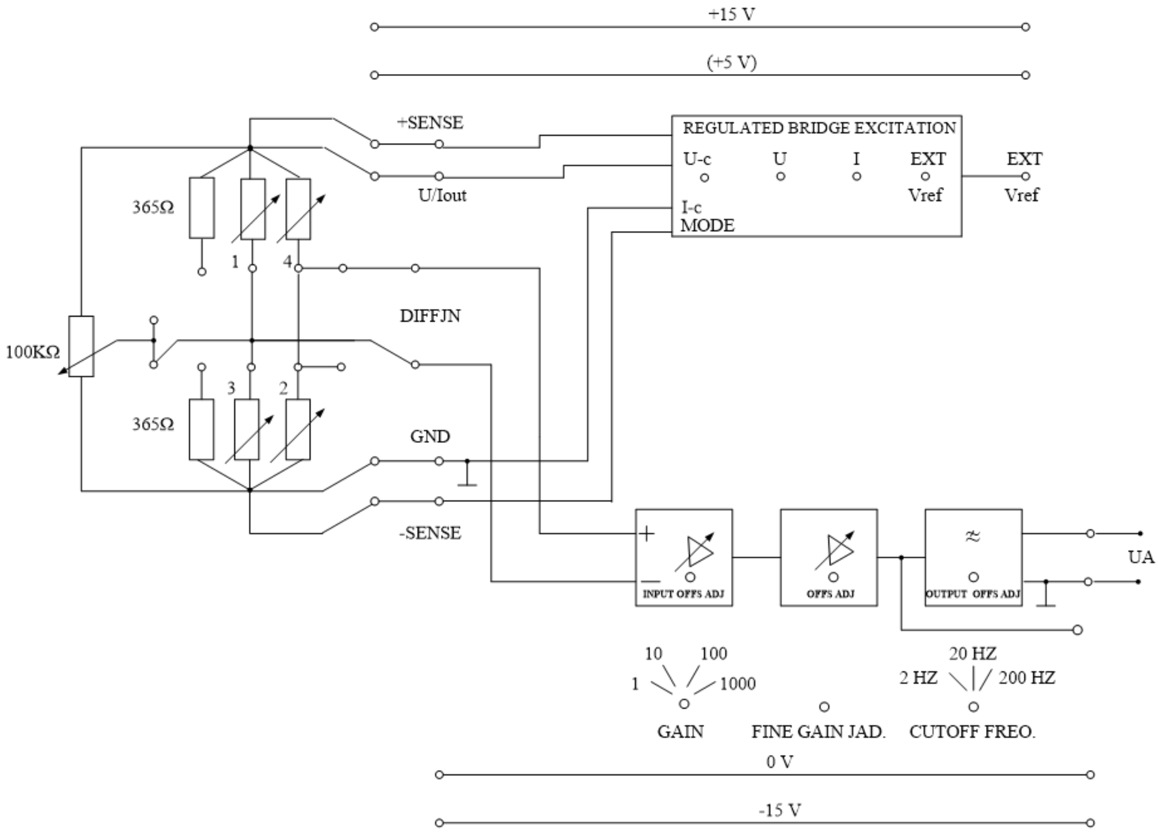

Figure 2.1: Circuit diagram for full-bridge circuit arrangement assembling with strain gauges.

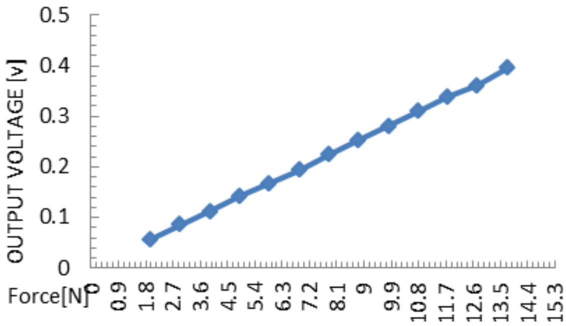

Figure 2.3: Voltage/force relation.

Table 2.1: Strain gauge calibration.

Weight	Output voltage	Weight	Output voltage
kg	V	kg	V
0.2	0.056	0.9	0.253
0.3	0.085	1.0	0.280
0.4	0.112	1.1	0.310
0.5	0.142	1.2	0.338
0.6	0.167	1.3	0.360
0.7	0.194	1.4	0.395
0.8	0.224		

In robots, the change in resistance is converted to equivalent voltage signal with the help of signal conditioning circuit. This voltage is proportional to force exerted on the strain gauge. Signal conditioning circuit consists of Wheatstone bridge as described in [16]. Known amount of weights are used to calibrate the gage. Weights ranging between 0 and 2 kilograms are used. These weights are applied on the strain gauge and the output voltage is measured. Table 2.1 represents strain gauge calibration for weights up to 1.4 kg. Figure 2.3 represents a linear relationship between weights and output voltages, where the linearity refers to the sensor's response (digital output) to the applied load (F).

2.2. Deformable objects (stress and strain)

The choice of material model is important and may not always be obvious. To understand the behavior of the compliance materials, it is necessary to perform material testing. A good way to evaluate material behavior is to do tensile tests at different rates to show elasticity effects in the material. Some of the material properties are provided by the material supplier, but they need to be complemented with further material tests. The polymers used in this study are plastics thermoplastic as high density polyethylene HDPE material, supplied in granular form plastics thermosetting as Bakelite material and plastics elastomeric as Rubber material. The physical properties of these three materials are found in [17]. They are tested in compression at room temperature at 20 ºC as a function of strain-rate.

The mechanical properties of polymers are specified with many of the parameters, that is, modulus of elasticity, and yield (critical) and tensile strengths. For many polymeric materials, the simple stress–strain test is employed for the characterization of some of these mechanical parameters. The mechanical characteristics of polymers are mostly very sensitive to the rate of deformation (strain rate), the temperature, and the chemical nature of the environment (the presence of water, oxygen, organic solvents, etc.). Tensile tests with constant displacement rate were performed on all test specimens for comparison with the simulated tensile test results.

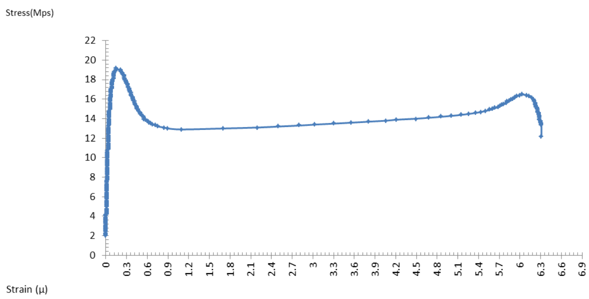

Figure 2.4: Stress-strain curve for a typical grade of HDPE.

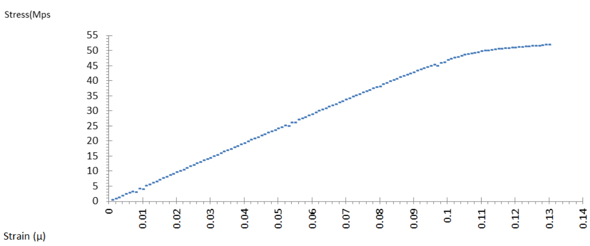

Figure 2.5: Stress-strain curve for a typical grade of phenol-formaldehyde (Bakelite).

Figure 2.4 shows the stress-strain curve for a typ-

ical grade of HDPE. To describe elastic properties of linear objects whether it is in the form of expansion or compression. A convenient parameter is the ratio of the stress /strain of 0.8 Gps and yield strength as the critical point is 19.1 Mpa. Figure 2.5 shows the stress-strain curve for a typical grade of Bakelite and represents elastic properties of linear objects whether it is in the form of expansion or compression, a convenient parameter is the ratio of the stress/strain of 35 Gps and yield strength as the critical point is 47.9 Mps.

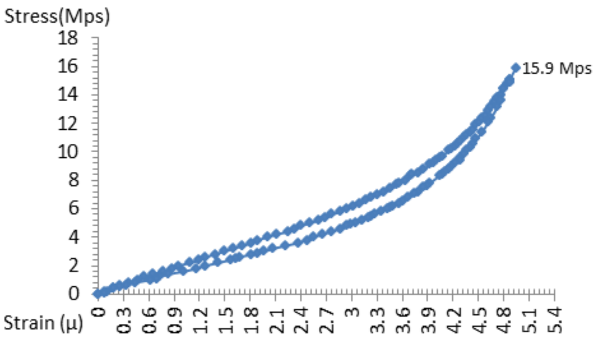

Figure 2.6: Stress-strain curve for a typical grade of natural rubber.

Figure 2.6 shows the stress-strain curve for a typical grade of natural rubber. To describe elastic properties of linear objects whether it is in the form of expansion and compression, a convenient parameter is the ratio of the stress to the strain of 0.002 Gps. The deformation displayed by stress and strain curve is totally elastic and totally nonlinear; this elasticity (large recoverable strains produced at low stress levels) .

3. Simulation Results and Discussion

When comparing the stress/strain relationship of the beam (gripper) to the stress/strain relationship of the gripped objects (compliance materials) we find that there is a linear relationship between stress/strain of the strain gauge in the range of 3.71 Mps to 70.83 Mps. Such a range covers the yield stress values of all the compliance materials. This range between 9 Mps for LDPE and 44 Mps for Nylon. For example, the standard yield stress for HDPE is 26.2–33.1 Mps [17] which almost agrees with analytical beam (Gripper) Yield stress of the 19.1 Mps under 5.0994 N an effect force with output voltage 0.1445 V and strain of 92.381 με as presented in Figure 3.1.

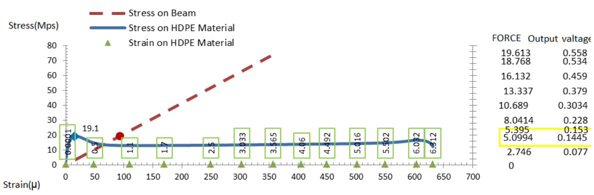

Figure 3.1: Stress/strain of the beam (gripper) and the gripped object HDPE materials.

Figure 3.2 represents the yield stress for Bakelite. The standard tensile stress for Bakelite is 34.5–62.1 Mps [17]. This value almost agrees with analytical beam (Gripper) yield stress of the 47.9 Mps under 12.749 N an effect force with output voltage 0.362 V and strain of 230.954 με.

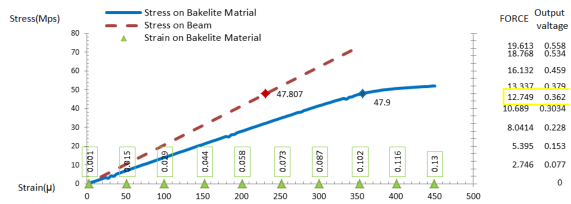

Figure 3.2: Stress/strain of the beam (gripper) and the gripped object (Bakelite).

It is clear from Figure 3.3 that the material of natural rubber has no critical point (yield stress) and is totally nonlinear. It is concluded that for flexible materials (Elastomers) the force required to grip is hard to be determined and therefore other means are required.

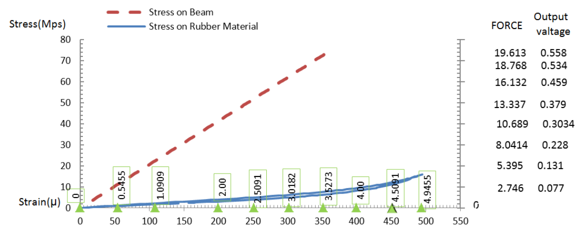

Figure 3.3: Stress/strain of the beam (gripper) and the gripped object (NR materials).

4. Conclusion

The paper presents an experimental procedure done on three selected flexible objects (High Density Polyethy-

lene, Phenol-Formaldehyde, and Natural Rubber) at 20 ^{o}C to find the stress point for the objects without damage. The procedure depends on the mechanical properties of polymers and uses strain gauge force sensors (1 N to 20 N) equipped on steel rod to measure the force and strain of selected objects.

The results show that the Bakelite has the highest tensile strength whereas NR and HDPE have the lowest. We can conclude that polymers with higher Young's modulus usually exhibit low or no yield strength as high Young's modulus material is rigid. Bakelite is the strongest, as it withstands large amount of force before it reaches the breaking point. However, Bakelite can easily reach the breaking point almost immediately once the maximum load is applied. HDPE, on the other hand, requires less amount of force to break, but it exhibits longer time to break for yield even when a maximum force is applied. We can also conclude that the combination of high tensile strength and high yield strength can lead to tougher material. Tensile properties are important to determine which material is suitable for a specific application.

References

[1] G. Garcia, J. Corrales, J. Pomares a Torres, F. Survey of Visual and Force/Tactile Control of Robots for Physical Interaction in Spain. *Sensors (ISSN 1424-8220)*, 2009, Vol. 9 (12). Pp. 9689-9733.

[2] H. J. Warnecke; I. Smith. Flexible grippers for handling systems design possibilities and experiences. *Fifth I.C.P.R.*, Chicago, August 1979, pp. 320–324.

[3] P. K.Wright; M. R. Cutkosky. Design of gripper. Handbook of Industrial Robot, 1985, pp. 96–111.

[4] J. Hollerbach. Grasping in Human and Robot Hands. *Vision and Action: The Control of Grasping, Ablex Publishing Corp*, 1990, Norwood, NJ.

[5] United States. Office of Technology Assessment. Computerized Manufacturing Automation: Employment, Education, and the Workplace. *Washington, GPO*, 1984.

[6] http:/www.wiley.com/college/callister/047012 5373 /vmse/strstr.htm, 1/6/2012

[7] D. Siciliano; L. Sciavicco; L. Villani, G. Oriolo. Robotics: Modelling, Planning and Control. 3rd Ed., Springer, 2009.

[8] S. Fatikow, Ed. Automated Nanohandling by Microrobots. *Springer Series in Advanced Manufacturing. Springer Verlag*, 2008.

[9] D. Geib. Multiplexing of Extrinsic Fabry-Perot Optical Fiber Sensors for Strain Measurements. *Thesis in Electrical Engineering, Virginia Polytechnic Institute and State University*, 2003.

[10] K. Hoffmann. An Introduction to Measurements Using Strain Gages. *Hottlnger Baldwin Messtechnick GmbH, Alsbach, Germany*, 1989

[11] C. S. Lynch. Strain Measurement. CRC Press LLC ,1999.

[12] Strain guge and force measurement http://cnx.org/content/m13779/1.1/ , 1/6/2012.

[13] Using a strain-gauge transducer in a Wheatstone bridge configuration, http://www.eetindia.co.in/ARTICLES/2007NOV/PDF/EEIOL_2007NOV16 _TEST_SIG_TA.1/6/2012.

[14] F. Schmaljohann; D. Hagedorn; F. Loffler. Thin film sensors for measuring small forces. *Journal of Sensors and Sensor systems*, 2015, 4, 91-95.

[15] IMT2. LN LUCAS-NULLE COMPUNY, ORDER-NO: SO 5157-2N, http://www.lucas-nuelle.com 13/5/2016.

[16] Mokrane Boudaoud; Stephane. An Overview on Gripping Force measurement at the micro and Nano-scales Using Two-fingered Microrobotic Systems. *International Journal of Advanced Robotic Systems*, December 2013.

[17] William D. Callister, Jr; David G. Rethwisch, "Materials Science and Engineering an Introduction ", 9th Edition John Wiley & Sons, United States of America, 2014.