# Use of Strain Gage Techniques to Determine the Mechanical Properties of Polystyrene in Low Strain Conditions

**João Basso, bassojc@whirlpool.com**
Whirlpool Eletrodomésticos, D. Francisca 7200, Joinville – SC, Brazil

**Ricardo Pedro Bom, dem2rpb@joinville.udesc.br**
Universidade do Estado de Santa Catarina, Paulo Malschitzki s/n, Joinville – SC, Brazil

***Abstract.*** *A low cost, yet reliable, alternative technique to research mechanical properties of polystyrene in low strain conditions was developed using strain gage techniques. For the experimental development, an electric circuit for signal acquiring and amplifying, consisting of a Wheatstone Bridge and an operational amplifier was designed. A test specimen was loaded with stresses up to 10 MPa while the corresponding strain signals were acquired. From the Stress x Strain curves the elasticity module of the material was quantified. The experiment was repeated replacing the proposed circuitry by an industrial hardware dedicated to strain gage measurements. The material was subsequently submitted to standard tensile tests. For strains up to 2µm/mm, the results dispersion of data obtained through the proposed technique was significantly smaller than the one obtained through standard tensile tests.*

***Keywords****: strain gage, stress test, polystyrene, Wheatstone Bridge*

## 1. INTRODUCTION

The mechanical behavior of polymers is usually located at some intermediate point between elastic and viscous. Young's modulus of materials with this feature can be expressed by Equation 1, in which E' represents the elastic part of Young's modulus, also called the storage modulus, and E" represents the viscous part, or loss modulus.

$$E^* = E' + iE" \tag{1}$$

Dynamic-Mechanic Analysis tests are conducted by applying a sinusoidal force over a test specimen and observing the consequent mechanic strain. Many of these tests carried out on polystyrene based parts indicate that, at room temperature, the storage modulus of this material is from 10 to 100 times bigger than the loss modulus, meaning that this material presents a predominantly elastic behavior (Werland et al, 1998). Young's modulus of this material is usually found from 3.0 to 3.5 GPa (Kwok et al., 1996). Depending on the processes used to obtain test specimens, equipment features and test methods, however, one can find values as low as 1.8 or 1.1 GPa (Torres et al., 1998), (Coutinho et al., 2007) .

One method utilized to determine mechanic resistance of the material is the tensile test. This test outputs the strain response to the application of a certain increasing force on a test specimen, allowing information to be obtained, such as Young's modulus of the material and tensile strength, among others. Another widespread technique is strain gage measurement, in which material strain is calculated by the variation of an electric signal applied onto an appropriate transducer, named strain gage.

Such tests are conducted by attaching a strain gage onto the surface of the material to be characterized. The strain gage is a transducer that converts a mechanical strain into an electric resistance variation. It is made of a thin conducing wire placed over an insulating substratum, which is glued onto the surface of the material to be measured. The mechanic strains caused by the load are transferred to the strain gage wire, which suffers a deviation in its electrical resistance. One widely employed adhesive is cyanoacrilate (Angelini, 1999). It shows good adhesion to polymeric materials, except to PTFE, PE and PP based ones (Petrie, 2000). Such adhesives do not contain solvents and their adhesion occurs partially due to the mechanical molecular interlock with the surface, and partially due to strong intermolecular attraction forces (Billmeyer, 1984), (Miranda and Passos, 1998).

The tensile test poses restrictions to low strain measurements due to the settling and fastening of the pinches onto the test specimen, as well as other setup characteristics. Measurements in this initial band are subject to strong noises, which demand special care for data analysis, as per ASTM D638 standard. Besides, measurement through strain gages is the ASTM E837 recommended technique to investigate residual strains resulting from polymer parts manufacturing process (Khan and Wang, 2001), therefore the need of high repeatability in low tension levels. In this paper, strain gage techniques were used to study mechanical behavior of polystyrene in the strain interval from 0 to 2 µm/mm. These results were compared to ones from tensile stress in the same range.

## 2. EXPERIMENTAL DEVELOPMENT

For this paper, the Styron polystyrene 688G (DOW) was chosen. This material shows a flow index of 3.2 g/10 min. and a Young's modulus of 3.168 MPa, as informed by the supplier. The test specimens were manufactured by compression at 1.6 bar, at melt temperature of 200 ºC and cooled by 50 min until room temperature. The strain gage employed was a PA-06-125RB-120L (Excel Sensors), having an electrical resistance of 120 Ohms and a gage factor of 2.11. Strain gage and tensile stress tests were conducted to determine and compare Young's modulus of the material.

Test specimens were loaded with several static traction weights up to 10 MPa, while the electronic voltmeter captured the electric signal coming from the strain gages. In order to determine the correspondent strains at each load applied, many steps must be considered: load (MPa), strain (μm/mm), strain gage (ΔΩ), Wheatstone bridge (ΔV) and amplifier (ΔV).

In this experiment, the occurrence of any reaction with the adhesive that could cause a change to any of the mechanical properties of the test specimen material was not expected. The gluing and curing process, however, poses difficult reproducibility and, to minimize its inherited noise variables, this step was fully conducted by only one operator in a temperature controlled room. The relation between mechanic strain and electric resistance variation follows a linear proportion, given by a linearity coefficient Gf, specific for each strain gage, as measured and informed by the supplier. The mechanic strain $\epsilon$ (μm/mm) and the electric resistance variation (ΔR) are tied as indicated in Eq. (2).

$$G_f = \frac{\Delta R/_{R}}{\epsilon} \leftrightarrow \frac{\Delta R}{R} = \epsilon\, G_f \tag{2}$$

Three test specimens were tested through a Catman ML801 acquisition device using an AP815 connector board, all from HBM from Brasil, and on a temporary loan from Whirlpool Corporation. Following, three other test specimens were tested through a simple electric circuit, consisting of a Wheatstone bridge and an operational amplifier. The Wheatstone bridge is a resistive circuit able to detect small variations in electric resistance of one or more of its components. These variations cause small shifts in the electric tension over each resistor. As these are very low variations, on a scale of thousandths of volt, this electric signal is taken to an amplifier, which will raise the signal amplitude up to levels that can be detected by some acquisition system. In this experiment, the electronic voltmeter DATAQ 158 and the Windaq Acquisition software were utilized. Figure 2 illustrates the electric diagram utilized in this experiment. All the required components are obtainable at costs well below those from industrial strain gage devices available on the market.

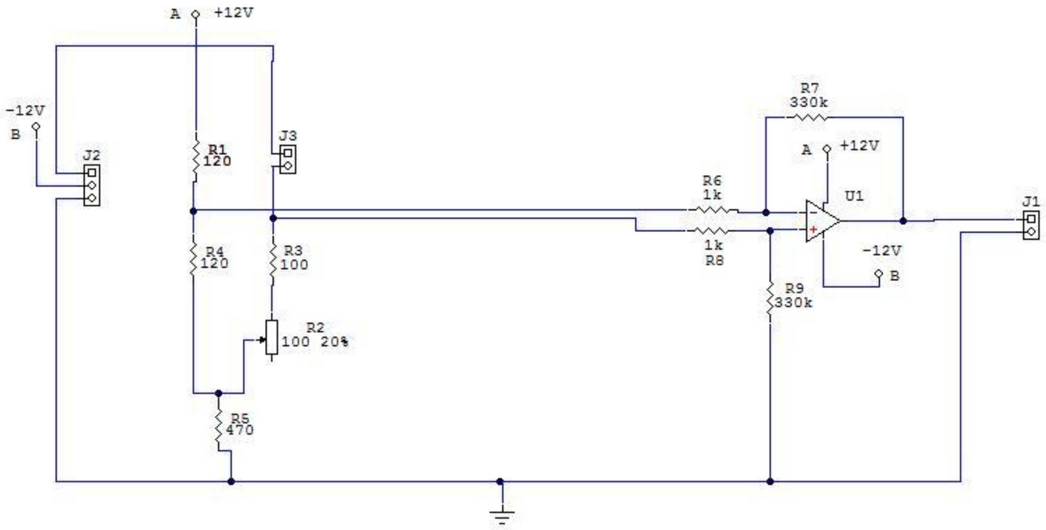

Figure 2: Acquisition system consisting of Wheatstone Bridge and Amplifier

The Wheatstone bridge was fed with a tension (Ve) of 2.4V. A strain gage was used as one of the bridge arms, while the other arms consisted of fixed resistors of 120 Ω. This arrangement, known as "quarter bridge", provides an output tension (ΔE) proportional to the gage electric resistance variation (ΔR) as in Eq. 3. The operational amplifier has a linear gain (Ga) of 330 times, equivalent to the ratio of resistors R7 and R6. This sequence allows the establishment of a relationship from the electric signal measured in the amplifier output and the strain in the gage, as indicated by Eq. 4.

From Hooke´s Law and knowing the test specimen transverse section area, determined in 38.1mm2, one can determine the tension applied over it and the Young’s modulus of the material per Eq. 5.

$$\Delta E = \frac{V_e}{4}\frac{\Delta R}{R} = \frac{V_e \varepsilon G_f}{4} \tag{3}$$

$$\frac{\Delta E}{\varepsilon} = \frac{V_e G_f G_a}{4} \tag{4}$$

$$\sigma = E\,.\,\varepsilon \tag{5}$$

Following, tensile tests were conducted according to standard ASTM D638, at a speed of 5mm/min. The test specimens were obtained through the same process and material from the previous experiment. The traction machine was an EMIC DL30,000N. A clip-style strain gage, model Trd 6, was connected at the linear region of the parts having an initial length of 50mm.

## 3. RESULTS AND DISCUSSION

In the strain gage tests, the correspondent strains were calculated for each load applied, as well as the resultant Young´s modulus. Table 1 indicates the results of the first strain gage tests. Test specimens A, B and C were measured through the industrial device and named Strain Gage 1, while test specimens D, E and F were measured through the Wheatstone bridge and named Strain Gage 2.

Table 1: Results of Strain Gage Tests

| σ (MPa) | Strain Gage 1 | | | Strain Gage 2 | | |
|---|---|---|---|---|---|---|
| | A (μm/mm) | B (μm/mm) | C (μm/mm) | D (μm/mm) | E (μm/mm) | F (μm/mm) |
| 1.03 | 0.101 | 0.192 | 0.192 | 0.182 | 0.210 | 0.209 |
| 2.06 | 0.313 | 0.414 | 0.407 | 0.403 | 0.414 | 0.406 |
| 3.09 | 0.555 | 0.651 | 0.651 | 0.611 | 0.619 | 0.614 |
| 4.12 | 0.805 | 0.894 | 0.880 | 0.877 | 0.838 | 0.856 |
| 5.14 | 1.125 | 1.213 | 1.201 | 1.169 | 1.082 | 1.160 |
| 6.17 | 1.388 | 1.461 | 1.451 | 1.417 | 1.353 | 1.397 |
| 7.20 | 1.676 | 1.721 | 1.717 | 1.657 | 1.594 | 1.641 |
| 8.23 | 1.937 | 2.008 | 1.973 | 1.896 | 1.853 | 1.822 |
| 9.26 | 2.211 | 2.266 | 2.253 | 2.163 | 2.106 | 2.104 |
| Young's Modulus | 3.82 | 3.91 | 3.94 | 4.10 | 4.29 | 4.27 |
| Correlation | 99.92% | 99.94% | 99.94% | 99.95% | 99.89% | 99.89% |
| Emed (GPa) | 3.89 | | | 4.22 | | |
| s (Mpa) | 50.85 | | | 84.56 | | |

In the tested strain levels, the test specimens showed a predominantly elastic behavior, which means a correlation over 99% to the linear model of Equation 6. Figure 2 shows the results obtained in this test. It was observed that the three tests of Strain Gage 1 showed a lower elasticity modulus, when compared to the ones from Strain Gage 2. Then, a Student’s t-test was carried out to determine if there was a statistically relevant difference between both methods. For this purpose, the F-test was previously employed to verify if the samples showed equal variances. The probability of the equal variances hypothesis was only 0.53, thus it was rejected. Therefore, the T-test was carried out through the method of unequal variances at 95% confidence, resulting in a 0.014 coefficient. The hypothesis of random difference between the means was then rejected, concluding that the difference between the two acquisition methods was statistically relevant.

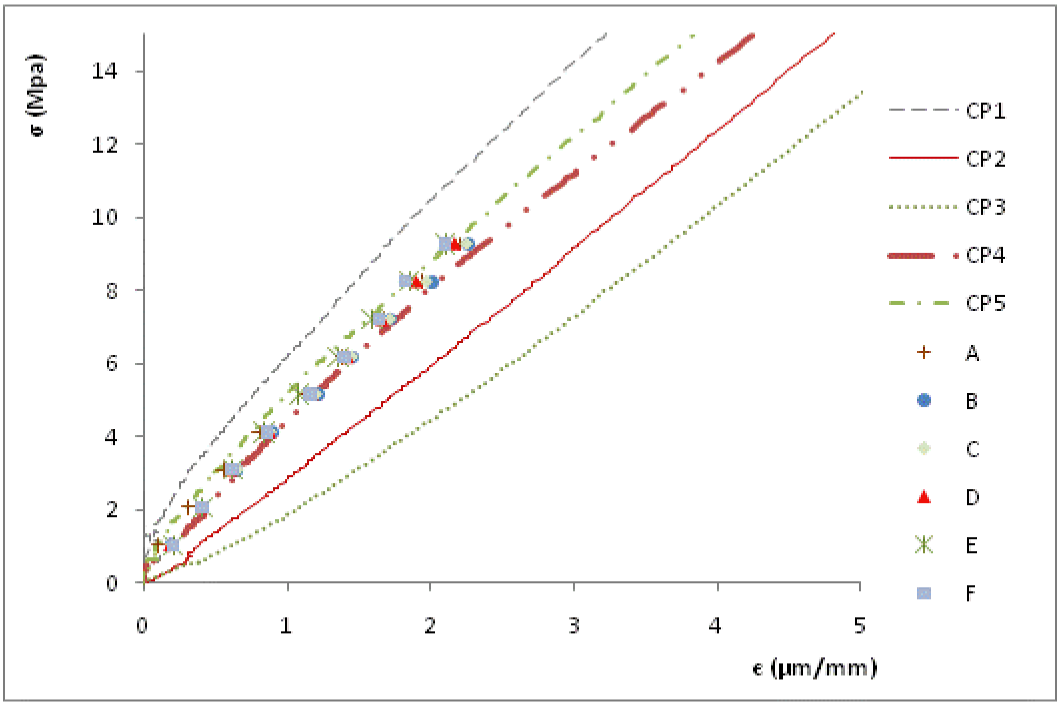

Figure 2: Tensile and strain gage tests results

In the tensile test, five test specimens were tested, per standard requirement of ASTM D638. The procedure from item A1.1 of that standard was followed to determine the elasticity modulus. The results are also plotted in Figure 2. The elasticity module found is stated in Table 2, as well as the correlation coefficients ($R^2$) and standard deviations.

Table 2: Tensile Test Results

| Run | TS1 | TS2 | TS3 | TS4 | TS5 |
|---|---|---|---|---|---|
| E (Gpa) | 3.81 | 3.17 | 2.97 | 3.11 | 3.31 |
| $R^2$ | 99.32% | 99.97% | 99.81% | 99.62% | 99.65% |
| $E_{med}$ (GPa) | | | 3.28 | | |
| s (Mpa) | | | 323.94 | | |

By comparing both sorts of tests, one can observe that the strain gage measurements showed a higher elasticity module than the ones from the standard tensile tests, as well as higher than what is found in the literature and informed by the supplier. Adhesive rigidity after cure is the most likely cause identified for this tendency, but such investigation would be out of the scope of this paper. It was observed, however, that the results dispersion obtained through strain gage techniques using an industrial device and a Wheatstone bridge were 5 to 3 times smaller than the one from the tensile tests, indicating that this method shows good discrimination for the comparison of different treatments applied to the same material, in a relative manner.

Just as with the strain gage measurements, the differences between variances observed in both experiments were analyzed in order to evaluate whether they are significantly relevant. Since there are three distinct groups, Student's t-test cannot be employed. Thus, Bartlett's test was utilized, resulting in a 14% probability that the variances of the three treatments are equal, leading to a rejection of this hypothesis.

Considering the hypothesis of unequal variances between groups, a Welch ANOVA was utilized to test the hypothesis of all means pertaining to a same group, that is, if there is any relevant difference between the elasticity module determined for each test. The F-ratio was calculated as 18.5%, rejecting the hypothesis of equal means with an error margin of 5%.

## 4. CONCLUSIONS

Based on the Wheatstone bridge classic topology and operational amplifiers, a simple and low cost circuit was developed, intended to acquire typical strain gage measurement signals. The strain gage tests carried out with this device showed significantly different results in the means and variances, when compared to results from a commercial device certified for industrial purposes. Therefore, results from both methods cannot yet be considered equivalent. However, the strain gage tests conducted with the device presented in this study showed results of the same magnitude as the ones taken with a commercial device. Linearity of the strain gage based tests showed to be higher than 99%, and dispersion observed was from 3 to 5 times smaller than the one from standard tensile tests, demonstrating this to be an useful method for comparative low strain measurements resulting from application of up to 10 MPa on polystyrene parts.

## 5. REFERENCES

Angelini, J. M. G.; Estudo de Tensões Residuais em Policarbonato Moldado por Injeção, Tese de Doutorado em Engenharia Química, Universidade Estadual de Campinas, Departamento de Tecnolgia de Polímeros, pp. 50, Campinas, 1999.

ASTM Standard D638; Standard Test for Tensile Properties of Plastics, A1.3, 1999

ASTM Standard E837, Determining Residual Stress by the Hole-Drilling Strain-Gage Method.

Billmeyer Jr, F. W. - Textbook of Polymer Science, John Wiley & Sons, Cingapura (1984).

Coutinho, F. M. B.; Costa, M. P. M.; Guimarães, M. J. O. C.; Soares, B. G.; Estudo Comparativo de Diferentes Tipos de Polibutadieno na Tenacificação de Poliestireno; Polímeros: Ciência e Tecnologia, 17, No. 4, 2007.

Khan, A. S.; Wang, X.; Strain Measurements and Stress Analysis, Ed. Prentice Hall, pp., 58, 2001.

Kwok, C. S.; Tong, L.; White, J. R. White; Generation of large residual stresses in injection moldings; Polymer Engineering & Science; 36, No. 5, 1996.

Miranda FA, Passos RR: Aplicação de Análise Multivariada aos Dados de Espectroscopia no Infravermelho Obtidos na Polimerização in situ de Adesivo à Base de Cianoacrilato. Polímeros. 1998;(Abr/Jun):41-45

Petrie, Edward M.; Handbook of Adhesives and Sealants, McGraw-Hill, 2000

Torres, M. A. P. R.; Telles, M. T.; Oliveira, C. M. F.; Avaliação das Propriedades de Misturas de Poliestireno com Oligômeros de Poli(Óxido de Propileno) e Poliestireno, Polímeros: Ciência e Tecnologia, 8, No. 3, 1998.

Werlang, M. M.; Araújo, M. A., Nunes, S.; Yoshida, I. V.; Miscibilidade de Blendas de Poliestireno com Polímeros de Silício, Polímeros: Ciência e Tecnologia, 8, No. 4, 1998.

## 6. RESPONSIBILITY

The authors are solely responsible for the content of this paper.