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# CHARACTERIZATION OF TEXTILE BASED STRAIN SENSOR

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**ABSTRACT**

A strain sensor was developed by In situ polymerization of pyrrole on elastic yarn through vapour deposition technique. A tosylate as doping agent and Iron(III) Chloride as oxidizing agent were used for the synthesis of polypyrrole. Change in resistance against the linear deformation was characterized and observed that comparatively high conductive samples show poor sensitivity and uniformity against 2% cyclic loading.

**KEYWORDS**

Polypyrrole; Latex/PA6 yarn; strain sensor; In situ polymerization; cyclic deformation.

## 1. INTRODUCTION

The conducting polymers (also called synthetic metals) are polyconjugated, which possess electronic (conductive, magnetic, optical) properties of metals, while retaining the mechanical properties and processibility of conventional polymers. They acquire high conductivity due to incorporation of a small concentration of dopants into the matrix of the initial polyconjugated polymers having conductivity ranging from $10^{-10}$ to $10^{-5}$ S $cm^{-1}$. The resulting materials have conductivities typical of metals or semiconductors, 1 to $10^{5}$ S $cm^{-1}$.

Electrically conducting polymer films can only withstand limited strain before breaking and cannot perform well in evaluating large strains (Murray, 1998). To overcome this problem, substrates were employed to provide the necessary support and the surface for conducting polymer film deposition. Generally, fabricating a strain sensor using this approach means that the mechanical properties are highly attributed to the substrate while the conducting polymer introduces the electrical conductivity. This practice is commonly found in the research field of smart textiles which are conductive fabrics produced by coating conducting polymers onto commercial fabrics such as nylon, polyester and Lycra (Li et al. 2005)(Xue et al. 2007)(Wu et al. 2005)(Molina 2008). Although excellent results have been demonstrated with smart textiles using conducting polymers, the intended applications are mainly aimed at enhancing the usability of fabric beyond its current use as a protective layer. As a general purpose strain sensor, the substrate requires having some degree of rigidity and fabrics are not an ideal material due to its soft structure. Furthermore, repetitive strain can cause permanent elongation on individual fibres where the strain may not be distributed equally. This can lead to individual fibres having different mechanical properties that will affect the strain sensing performance. The proposed solution is to replace fabric with Latex/PA6 stretchable yarn, which has good combination of rigidity and elasticity. One of the studies has succeeded in fabricating a strain sensor using PPy and natural rubber substrate where PPy powder is embedded into the structure of

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the rubber directly (Bunsomsit et al. 2002). Compared to the coating methods, that approach requires knowledge of rubber manufacture as well as an access to the equipment to produce rubber with consistent mechanical properties.

This work is aimed at developing a low cost, small to large strain sensor using PPy and Latex/PA6. This stretchable yarn was chosen as the substrate due to its excellent resilience and elasticity. Commercial Latex/PA6 strip was purchased and used to produce the strain sensor. PPy as thin film was coated onto this substrate by means of vapour phase polymerisation technique that provides a good adhesion between the two components of the strain sensing element.

## 2. MATERIALS

### 2.1. Latex/polyamide-6

For developing the strain sensor, PA6 wrapped Latex yarn produced by PEGA® Czech Republic, has been selected as a substrate for the deposition of PPy. The microscopic image is shown in Figure 1 and the specifications of this yarn are described in Table 1.

Table 1: The particulars of PA6 wrapped latex yarn

| Properties | | Index |
|---|---|---|
| Diameter of Latex [mm] | | 0.6 |
| (*)Effective diameter of whole thread [mm] | | 0.68 |
| Linear density of Latex [tex] | | 36.8 |
| Fineness of PA6 [tex] | | 22x3 |
| No. of turns of PA6 around Latex [$cm^{-1}$] | | 12 |
| Composition [%] | PA6 | 42 |
| | Elastodiene | 58 |

*: Yarn packing density was assumed as μ = 0.525 (Militky et al. 2004).

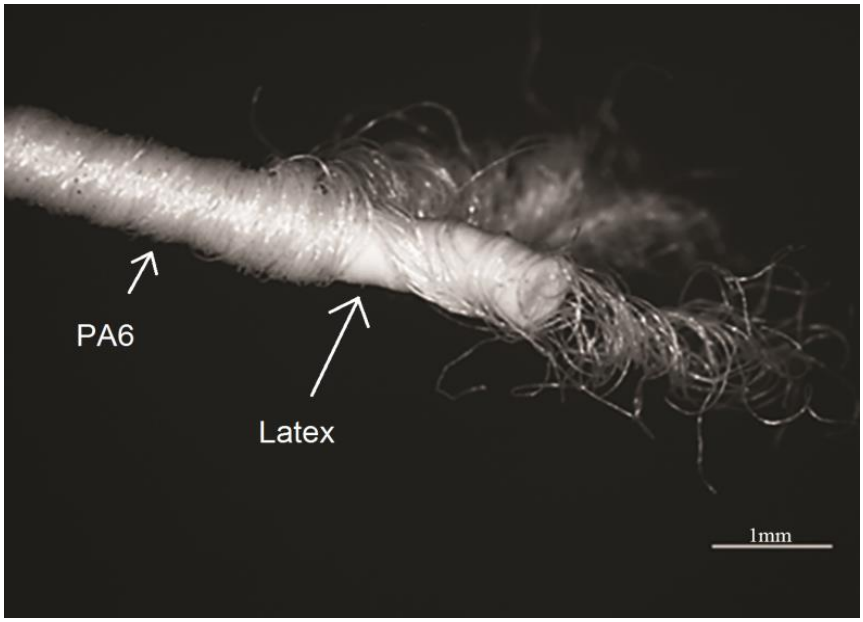



Figure 1: The microscopic image of Latex wrapped with PA6

### 2.2. Chemicals

Pyrrole is available in the market with different synonyms such as 1H-Pyrrole, Divinylenimine, Imidole, Azole, Monopyrrole, 1-Aza-2,4-cyclopentadiene. For this study Pyrrole 98% was received from Alfa Aesar® and was used after distillation to remove colouring impurities.

Anhydrous Iron(III) Chloride 97% was ordered from Sigma-Aldrich® and was used as received. It has molar mass 162.2 $g.mol^{-1}$ and 2.898 $g.cm^{-3}$ density. Tetraethylammonium p-toluenesulfonate also called tosylate ($TsO^-$) was obtained from Aldrich and was used as received.

## 3. METHODOLOGY

### 3.1. Sample preparation

An aqueous liquor bath was prepared using 2:1 molar ratio of $FeCl_3$ and $TsO^-$. This molar ratio between oxidant and dopant was optimized by the series of experiments in our previous work (Abbasi et al. 2013). As $FeCl_3$ follows exothermic reaction when comes in contact with water, ice was used to reduce the temperature of the solution around 20°C. The yarn sample was immersed in bath for 1 min followed by squeezing at 70% pickup (maximum pickup by yarn) with the help of pneumatic squeezing rollers. Sample was then placed with the help of holders in a glass desiccator filled with pyrrole vapours immediately after padding and squeezing. The temperature of desiccator was kept at 20±2°C and sample was remained into it for 6 h under ambient atmospheric pressure. Sample was then taken out and washed with ethanol in order to stop polymerization and subsequently with plenty of distilled water for several times to remove bi-products and unreacted chemicals. Finally sample was dried in air at 20±2°C for 24 h. Three different samples were prepared in exactly the same way by varying the concentration of $FeCl_3$ and $TsO^-$ as mentioned in the Table 2.

Table 2: Recipes for the preparation of PPy coated Latex/PA6 yarn samples.

| Sample label Latex/PA6 | Iron(III) Chloride ($FeCl_3$) [mol/L] | Tosylate ($TsO^-$) [mol/L] |
|---|---|---|
| SY1 | 2.0 | 1.0 |
| SY2 | 0.6 | 0.3 |
| SY3 | 0.1 | 0.05 |

### 3.2. Measurement of electrical resistivity of PPy coated Latex/PA6 yarn samples

With the intention of measuring electrical resistance *R* of PPy coated Latex/PA6 samples, stainless steel clamps were used to hold the sample together with connecting wires and a digital multimeter as shown in the Figure 2. The electrical resistivity $\rho$ of the yarn sample was calculated from the Equation 1, by knowing average cross-sectional area of the yarn sample "*a*" and the length of the sample "*L*" between two measuring electrodes A and B.

$$\rho = R\frac{a}{L} \tag{1}$$

With the objective of determining the dependence of electrical resistance on length of a sample, the resistance was measured by varying the distance from 5cm to 90cm between measuring electrodes.

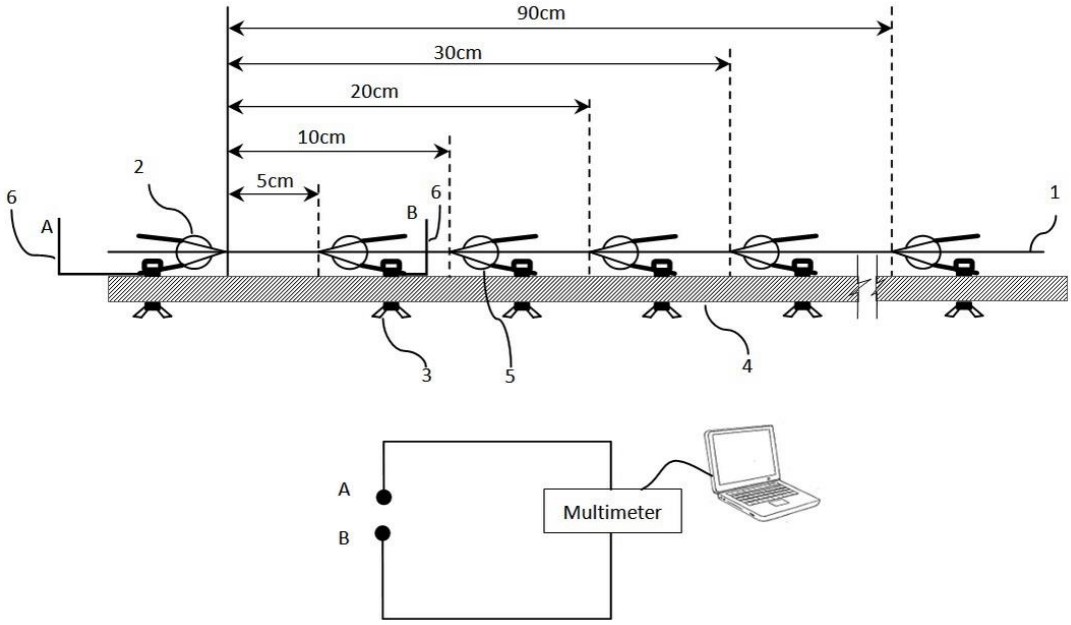



Figure 2: Schematic diagram of experimental setup for the measurement of electrical resistance of yarn (1) the sample (2) stainless steel clamp type electrode to hold sample (3) clamp supporting bolt and washers (4) supporting pad made of an electrically non-conductive material, (5) other electrode clamp with change in length of the measured section (6) wires connected to the electrodes and multimeter

### 3.3. Measurement of sensitivity of PPy coated Latex/PA6 yarn samples

With the objective of characterizing sensitivity of PPy coated Latex/PA6 yarn samples against deformation, all the samples from Table 2 were subjected to cyclic loading by using tensile testing machine Labtest from LaborTech® Ltd Czech Republic. The arrangement of the experiment environment can be seen in Figure 3. The cycle was set for 2% strain at the jaw moving speed of 100mm/min with a rest of 1 second at relaxed or initial position to synchronize normal human breathing rhythm.

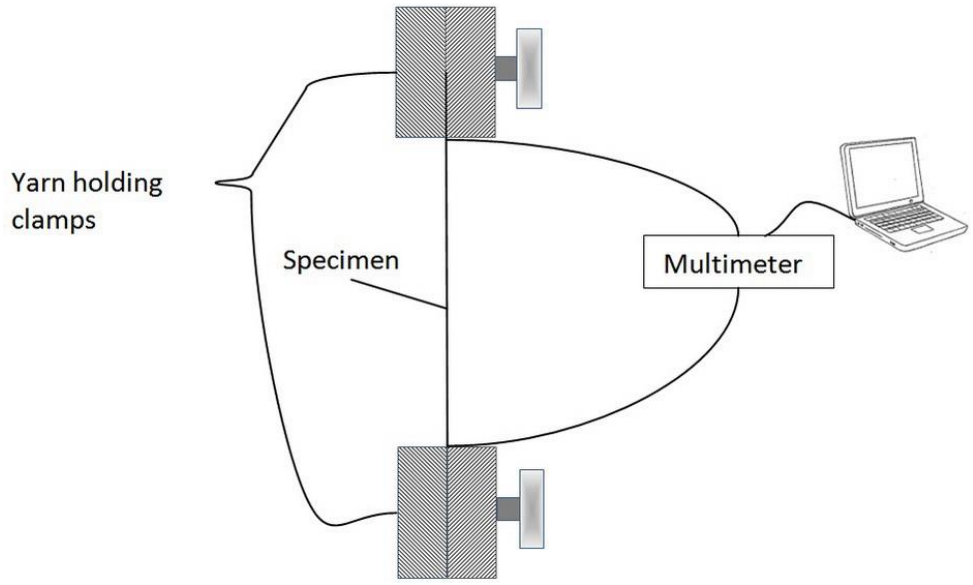


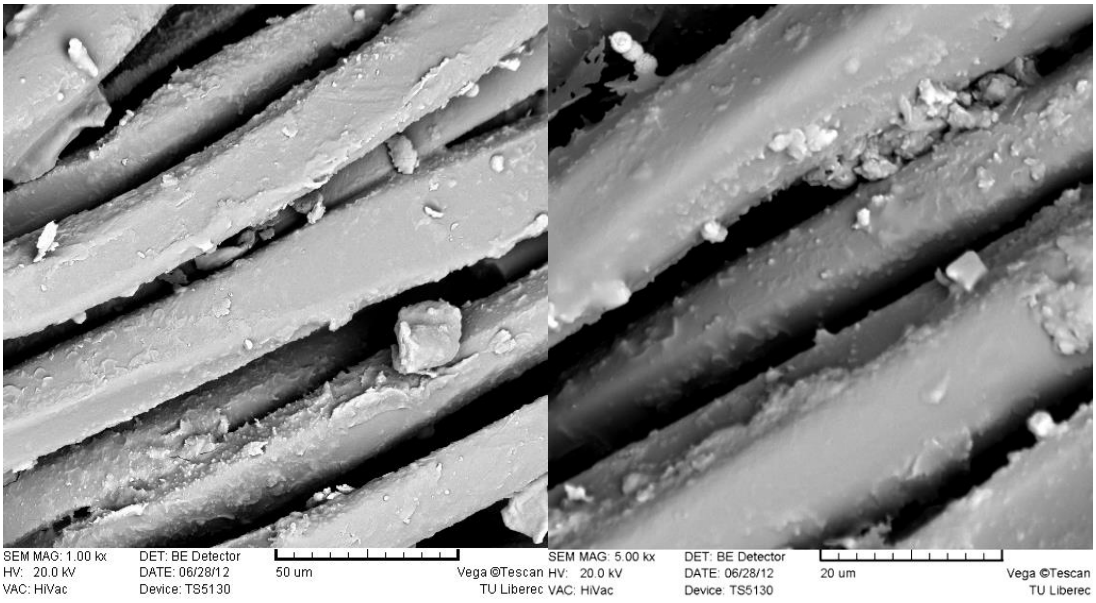

Figure 3: Experimental arrangement for measuring sensitivity at cyclic loading

One set of measurement includes 40 cycles, therefore in this way 5 sets of readings were recorded and sensitivity $dR/d\varepsilon$ of the yarn sample was monitored. Here *dR* is the average change in resistance ($R_1$-$R_o$) of the specimen calculated from 5 sets of 40 cycles during extension of 2% and $d\varepsilon$ is the change in length [mm]. $R_1$ is the resistance of specimen at 2mm extension whereas $R_o$ is the resistance at relaxation or initial point.

## 4. RESULTS AND DISCUSSION

### 4.1. SEM micrographs

The SEM micrographs were taken from TESCAN® VEGA and corresponding to sample SY3 is depicted in Figure 4. It can be perceived from the figure that by vapour deposition technique, each individual fibre is covered by PPy thoroughly, even though the structure of Latex/PA6 stretchable yarn is very compact as shown in Figure 1.




(a) (b)

Figure 4: SEM micrographs of PPy coated Latex/PA6 yarn sample SY3 (a) low magnification (b) high magnification

### 4.2. Linear dependence of resistance on length

In order to determine the dependence of resistance on the length of PPy coated Latex/PA6 yarn, sample was clamped between two stainless steel clamp type electrode and resistance was measured by varying the distance between them as described earlier. It was found that resistance of PPy coated Latex/PA6 stretchable yarn is a linearly increasing function of the distance between the electrodes holding the yarn as shown in Figure 5. By the least squares regression for this model this relationship can be expressed as:

$$R=ZD+r \tag{2}$$

where, *R* is the resistance [kΩ] of PPy coated Latex/PA6 yarn sample, *D* the distance between measuring electrodes and *r* the resistance of the electrodes found to be 0.0001kΩ approx. in this work. However the slope Z is the directly proportional to the resistivity $\rho$ in [kΩ.cm] of the PPy coated Latex/PA6 yarn samples as shown in the Figure 6 for this experiment and can be calculated as:

$$Z=275.63\cdot\rho-0.0769 \tag{3}$$

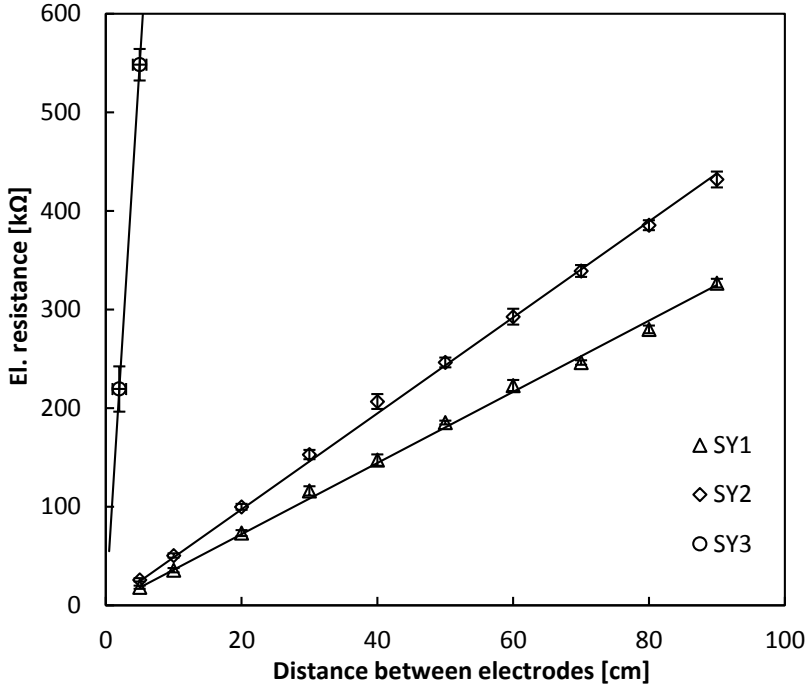



Figure 5: Dependence of electrical resistance of PPy coated Latex/PA6 yarn samples on length

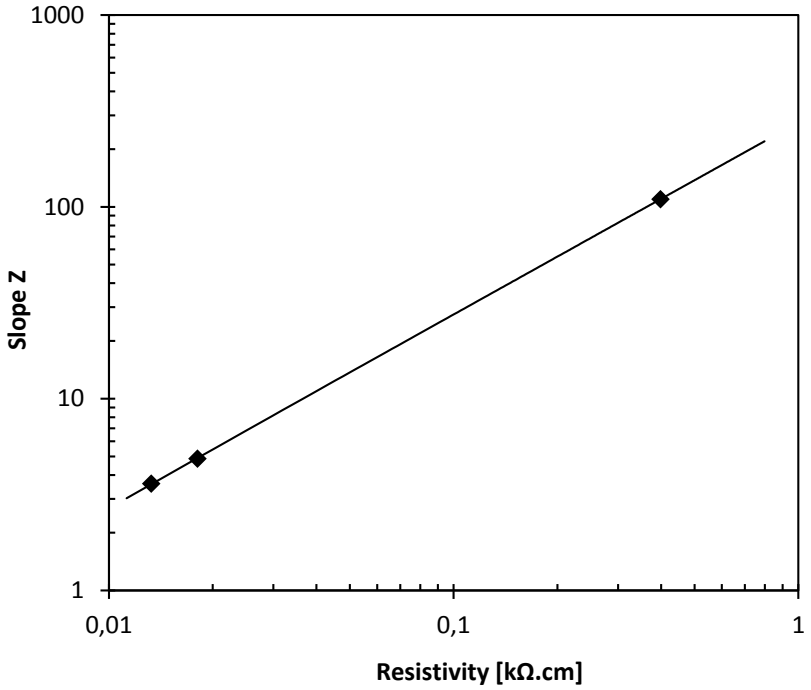



Figure 6: Relationship between slope Z and resistivity of the samples

### 4.3. Sensitivity of strain sensor against cyclic loading

The Latex/PA6 stretchable yarn samples were coated by PPy through vapour deposition technique and each PPy coated sample was subjected to cyclic loading for 40 cycles. The response of resistance of the samples on 2% deformation and relaxation during 40 cycles are plotted in Figure 7.

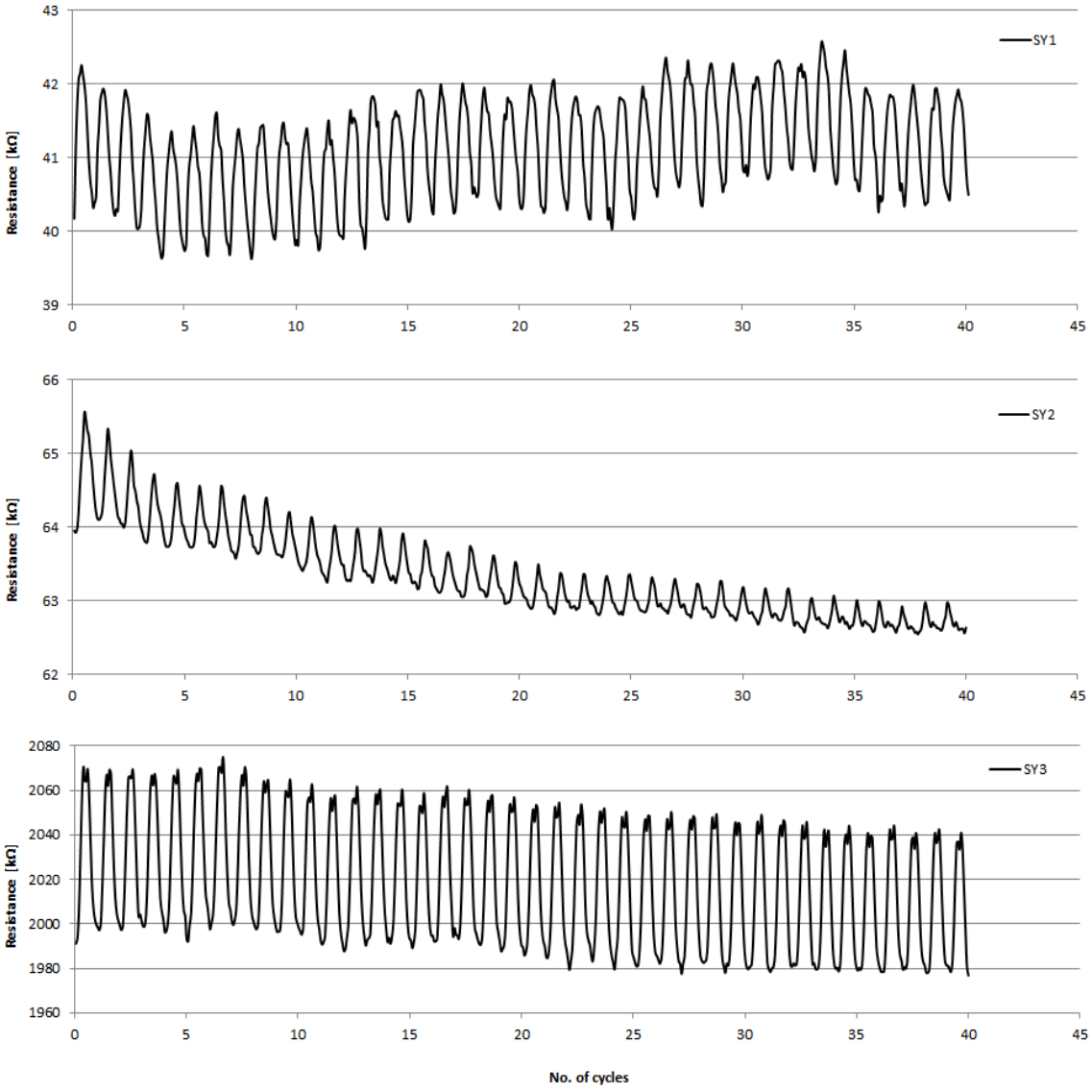



Figure 7: Response of PPy coated Latex/PA6 samples at 2% deformation for 40 cycles

From the Figure 7Figure it can be observed that SY1 gives almost equal response dR against deformation in terms of magnitude but this response is not consistent with the number of cycles. The SY2 gives neither an equal response against deformation (decreases with number of cycles) nor the consistency of the response. Whereas SY3 is the best among all the samples and it gives not only an equal response upon deformation but also the level of consistency of the response after each cycle is outstanding. The average response in terms of change in resistance against deformation has been calculated from 40 cycles and named as sensitivity $\left(dR/d\varepsilon\right)$ of each sample. The sensitivity levels of all PPy coated Latex/PA6 samples are shown in Figure 8.

Although SY3 has the highest resistivity among all three samples under study, however it outperformed SY1 and SY2 in terms of response against small extension. The sample SY2 has been found as the worst in terms of sensitivity and its deviation in the results. The standard deviations of the specimens were calculated as 0.182, 0.315 and 4.49 [kΩ.cm] for SY1, SY2 and SY3 respectively.

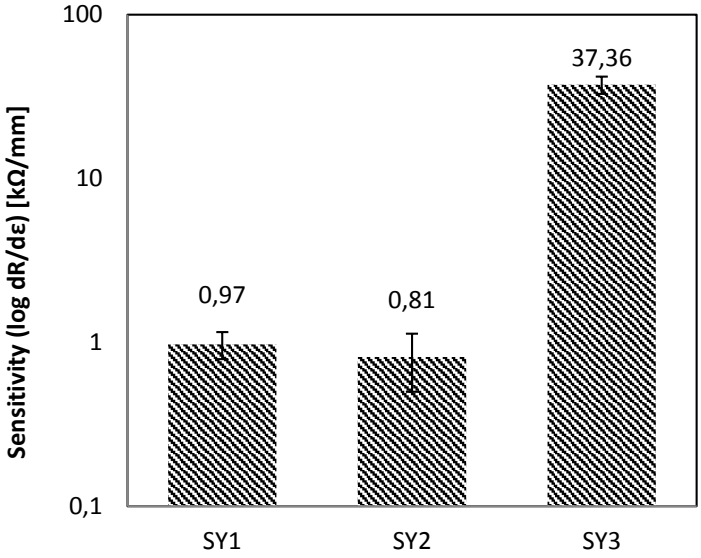



Figure 8: Dependence of sensitivity of the strain sensor on longitudinal deformation

In addition to the high sensitivity, uniformity or the stability of the response on multiple loading is also important factor for practical applications. The uniformity can be analysed qualitatively from the plotted graphs of strain-resistance relationship such as shown in Figure 9.

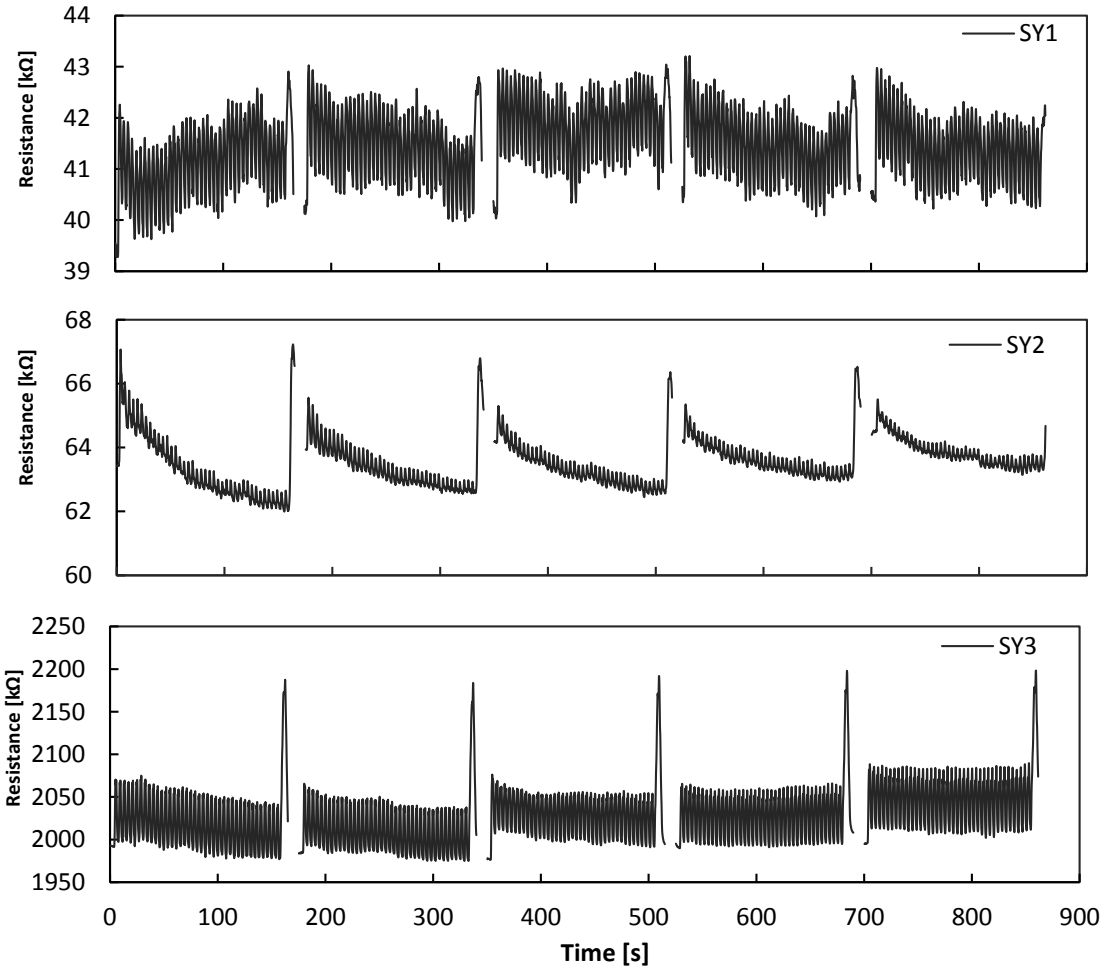



Figure 9: Responses of resistance of different samples at 2% elongation with multiple sets of 40 cycles

When the PPy coated Latex/PA6 yarn sample is elongated, the force is provided by an external motor of the testing rig that separates adjacent PPy grains which lead to the increase in electrical resistance due to the reduction in the available paths for the charge carriers. During the retraction stage the motor releases strain and the retraction force is provided by the Latex itself. Changes in the electrical resistance rely on the resilience property of the Latex to store the applied strain and utilize the stored energy to mirror the elongation stage. There is random shift in the electrical resistance observed in case of SY1 and downward shift in case of SY2 whereas deviation of amplitude from the mean on cyclic loading is not so huge in terms of SY3 and gradient remains constant.

## 5. CONCLUSION

PPy was coated on PA6 wrapped Latex yarn samples through vapour phase polymerization by varying concentration of oxidant and dopant thus samples were varied in resistivity levels. It was found that resistance of all the samples follow exactly a linear function of length and hence follow Ohm's law.

The sensitivity or the change in resistance per unit deformation is a useful tool to figure the suitability of the strain sensor out. The high resistive sample gives best sensitivity as well as uniformity or the consistency of the response against small cyclic deformation (2%) whereas low resistive samples fail to give the equal and uniform response. Therefore it is suggested that this product can be used to monitor human body movements even for very small deformations such as breathing.

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