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The behaviour of different design of flexible force sensor based velostat during implementation of static load with different contact area

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ABSTRACT

Great attention has been given to flexible force sensors and the materials that have been used as a sensing material by studying their properties and evaluate their behaviours with different types of loads. Velostat is one of the most promising sensing materials that has been widely studied and evaluated for different applications due to their distinct traits of flexibility, suitable cost as well as their ability to cover the wearable applications. This work makes focus on the behaviour of Velostat flexible force sensor by measuring the resistivity of the sensor while applying loads with different contact area. Two different designs of sensor have been studied, which are the single output flexible force sensor and multioutput matrix flexible force sensor, by applying loads starting from 0.98 (N) to 9.8 (N) with four compression disc having different diameters. It has been found that the two design behave in opposite manner. The resistance of the single output design decreased as the contact area increased, while the matrix design showed an increasing in the resistance as the contact area increased.

Keywords: Velostat flexible force sensor, single output flexible force sensor, multioutput matrix flexible force sensor

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1. Introduction

Flexible force sensitive resistor (FSR) is a remarkable topic of pressure sensor due to its competence to cover a wide range of applications starting from basic application in pressure sensing like pressure evaluation, force distribution on the surface and tactile sensation up to modern wearable electronics applications [1].Polymer based materials are promising, reliable, and stable for the designing of pressure sensor due to their ability to change their physical properties according to the applying load, that make the materials electrical conductivity highly sensitive to the pressure [2].

One of the interesting choices for a resistive sensor that has the capability to cover wide applications is the Velostat material. The Velostat is a semiconductive polymeric based foil material suitable for designing flexible pressure sensors due to its flexibility and good physical properties. The main advantages of Velostat are the acceptable dynamic range, simplicity of manufacturing, availability in small thickness, stability of its mechanical and chemical properties and power consumption, furthermore its low price [3]. All these specifications make the Velostat to be developed from alternative to traditional material in designing the force sensor. Among all previous fields, Velostat main field is the flexible sensor design which have a grate implementations in robotics, wearable sensors, human-machine interaction devices [2]. Velostat is a composite polymer material consisting of impregnated carbon nanoparticle inside the polyethylene where the carbon conductivity helps to overcome the dielectric property of polyethylene and turn it to piezoresistive group [4].

Two physical phenomena can explain the piezoresistive sensitivity of the Velostate, which are: quantum tunnelling and percolation. In quantum tunnelling phenomenon, the conductivity of the composite material is affected by the tunnel effect when the conductive particles change their interspaces according to the applying

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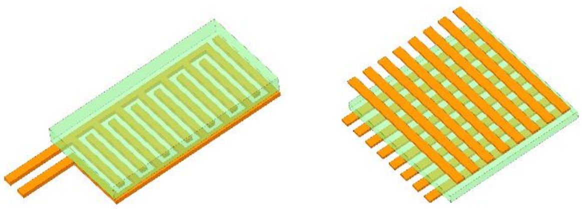
load that deform the material. This mean that the interparticle tunnelling effect make the conductive particles electrically connected without any physical interaction within geometry. Thus, the electrical resistance of Velostat has been changed when mechanical bending, tension, or pressure are applied due to the above-mentioned effect [5].

In percolation phenomenon, direct conductive path can be generated or destroyed due to the deformation which modify contacts between particles. The threshold between the dielectric state and conductive state is highly influence the pressure sensing of the material. The percolation threshold calculates by the amount of the conductive filler sparse inside the matrix which is highly affected by the deformation caused by the applied load [5]. In this work, two different design of flexible pressure sensor based on Velostat has been tested to evaluated

1.1. Pressure sensor design

Different application can be used the same piezoresistive material but with different design due to the variation of the shape, covering area, volume and electrode distribution of the sensor [6]. To make a resistive pressure sensor, two main components are needed. The first is the piezoresistive material which are the core of the sensor and the last is the two electrodes which are made of conductive material that arranged in a way so that the current will be passed from the first electrode to the second electrode passing through the piezoresistive material. There are two main groups regarding to the electrode arrangement of pressure sensor which are single output sensor and matrix sensor as shown in Figure 1. More than two design of sensor regarding to each group [5] , but in this study only one from each group has been chooses.



a b

Figure 1. Sensor design. (a) Single output sensor design. (b) multioutput matrix sensor design

The chosen design of the first group has been arranged by placing both electrodes side by side and on the same side of the composite Figure 1a. This design is a sensor able to sense pressure or force in a small area; therefore, it has a single output and having small size and low cost. Regarding the second group, electrodes matrix has been arrange based on horizontal and vertical that are placed on both side of the sensing material Figure 1b. This design is more appropriate when a pressure distribution map is needed instead of the information from a single point.

1.2. Equipment

Figure 2 shows the testing equipment that has been used which has the following main parts:

1- Outer frame
2- Testing plate
3- Two hex nuts
4- Four scale sensors
5- Stepper motor
6- Belt
7- Compression disc.

Four scale sensors (part 4) have been attached to testing plate (part 2) and fixed over the base of the frame (part 1). A rotatable screw (part 3) has been attached to the upper part of the frame with tow hex nuts (part 4). The screw has been rotated in steps mode using 42HD4027-01-A Torque 0.4N·m stepper motor (part 5) and belt (part 6).

This motor rotates 1.8 degree per step which has been controlled using stepper motor driver TB6600 with a setting of 1/16 step mode in order to increase the accuracy of rotation which has great effect on the accuracy of the amount of the applying load. Compression discs (part 7) with different diameter (28mm, 20mm, 14mm and 8mm) have been used during the tests so the same different loads have been applied bay different contact area.

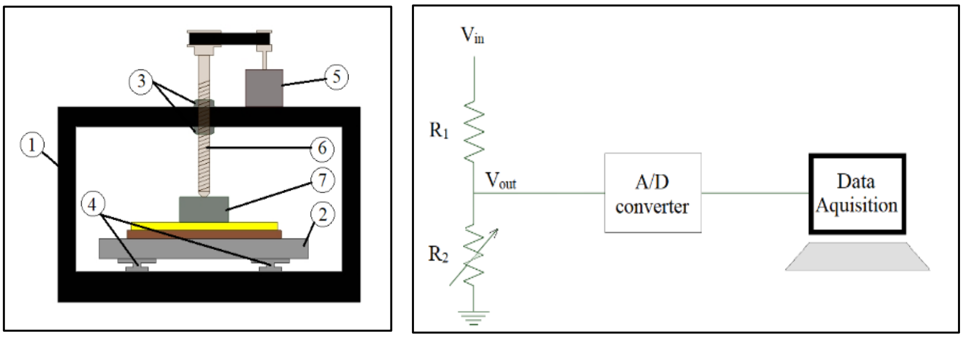


Figure 2. Compression test equipment

To apply a specific amount of load, the pressure sensor has to be applied between the compression disc and the testing plate, then the stepper motor has been moved by a specific number of steps which has been calculated previously to make the screw apply a compression needed.

2. Methodology

2.1.1. Testing method

The Velostat sensor has been placed on the testing plate and a normal force has been applied by the compression disc. The sensor starting the test with a load equal (0.98 N) and a compression disc diameter equal (0.8 mm). After about (250 msec) of the applying load, the measurement of the sensor's resistivity will be stared then the load will be released after a short time. The same sensor will be tested again after 25~30 sec by a new load with an increment equal 0.98N until reaches the 9.8 N. After testing the sensor with ten different amounts of load (from 0.98N to 9.8N with an increment +0.98N), the sensor has been left at rest for about 15 minutes and then all the above steps will be repeated but with a new compression disc which has a greater diameter (14 mm, 20 mm, 28 mm) subsequently. In short, the complete test includes four sessions, each session the sensor resistivity will be measured ten times for ten different loads and after 15 minutes new session will be started.

2.2. Resistance measurement

The measurement of the FSR resistance has been achieved by measuring the voltage between two resistanceR_1 and R_2, where R_1 is a known resistor that connected to Vin (+5V) and R_2 is the unknown resistor of the FSR which are connected between R_1 and the ground. An Arduino has been used for the measurement of the V_{out} using its analog pin as well as using it as an A/D converter in order to send the data to the data acquisition system.

Choosing Arduino inferior to digital ohmmeter was due to the ability of sending the data directly to the computer rather than the simplicity of using the multiplexer/demultiplexer in order to measure (256) sensor points for (16*16) sensor matrix in short time (less than 300 msec) which is so important to reduce the creep effect of the velostate during the loading time. Four different values have been used for R1 (9.7 kΩ, 2.2 kΩ, 656 kΩ and 100 kΩ) in order cover the dynamic range of the FSR resistance during different applying loads and for different pressure area. The proper value for R1 has been chosen using dip switch with 4 toggles.

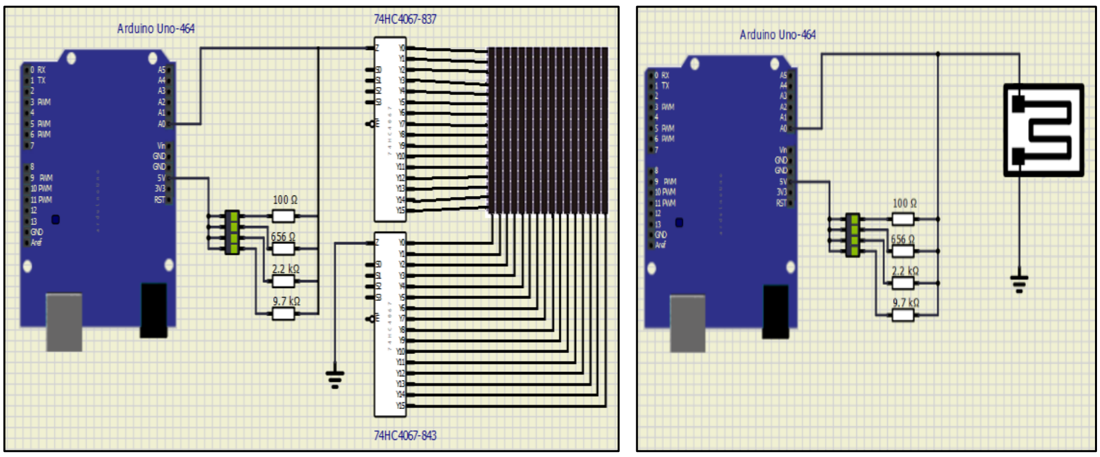


Figure 3. Schematic diagram for resistance measurement circuit. (a) Measurement circuit for the multioutput matrix sensor. (b) Measurement circuit for the single output sensor design

3. Results and discussion

Figure 4, Figure 5, Figure 6 and Figure 7 show the experimental results for static evaluation of applying ten different loads using four compression discs having different diameters. In Figure 4 and Figure 5, the curves represent the relation between resistance of the Velostat related to the applying load for specific contact area according to the diameter of the compression disc that has been used during the test. In Figure 6 and Figure 7 the curves represent the resistance reading of the sensors related to specific load value but for different compression disc diameters.

All these curves for Figure 4 and Figure 5 reflect the standard behavior of the Velostat material where the resistance curve has been decreased as long as the load has been increased. From the observation of each curve of Figure 4 separately which represent the reading of the single output design of sensor, it can be found that the maximum resistance that has been recorded was (865 Ω) for the lowest applying load as in Figure 4d, which represent data of compression disc with (8 mm) in diameter, while the lowest resistance value was (87 Ω) for the highest applying loud for the Figure 4a which represent data of compression disc with (28 mm) in diameter.

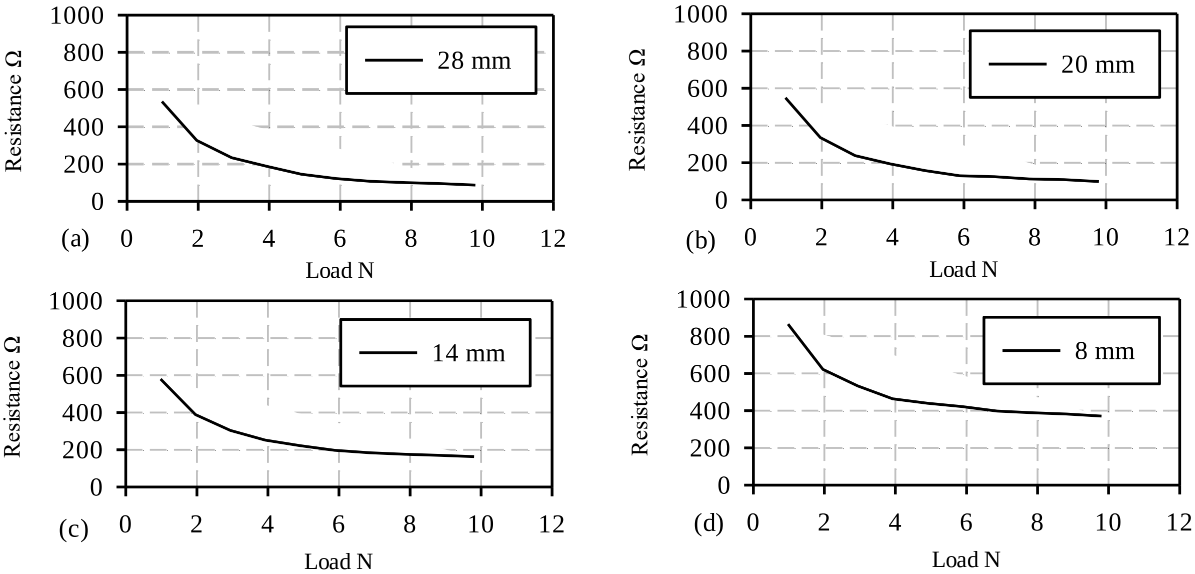


Figure 4. The resistance reading of single output sensor design during static load test for four different diameter of compression disc. (a) compression disc with diameter = 28 mm. (b) compression disc with = equal 20 mm. (c) compression disc with diameter = 14 mm. (a) compression disc with diameter = 8 mm

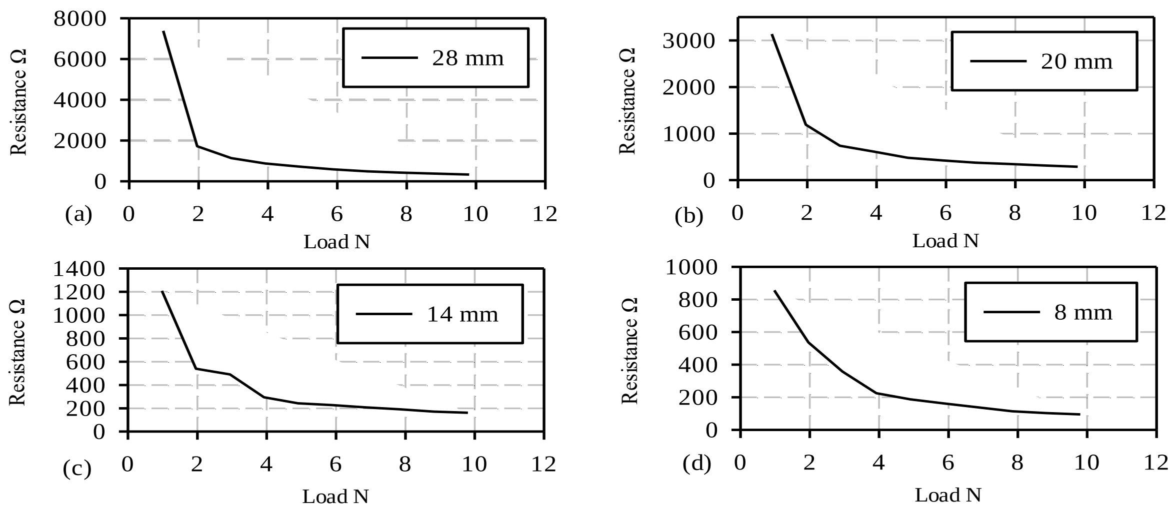


Figure 5. The resistance reading of multioutput matrix sensor design during static load test for four different diameter of compression disc. (a) compression disc with diameter = 28 mm. (b) compression disc with diameter = 20 mm. (c) compression disc with diameter equal 14 mm. (a) compression disc with diameter = 8 mm

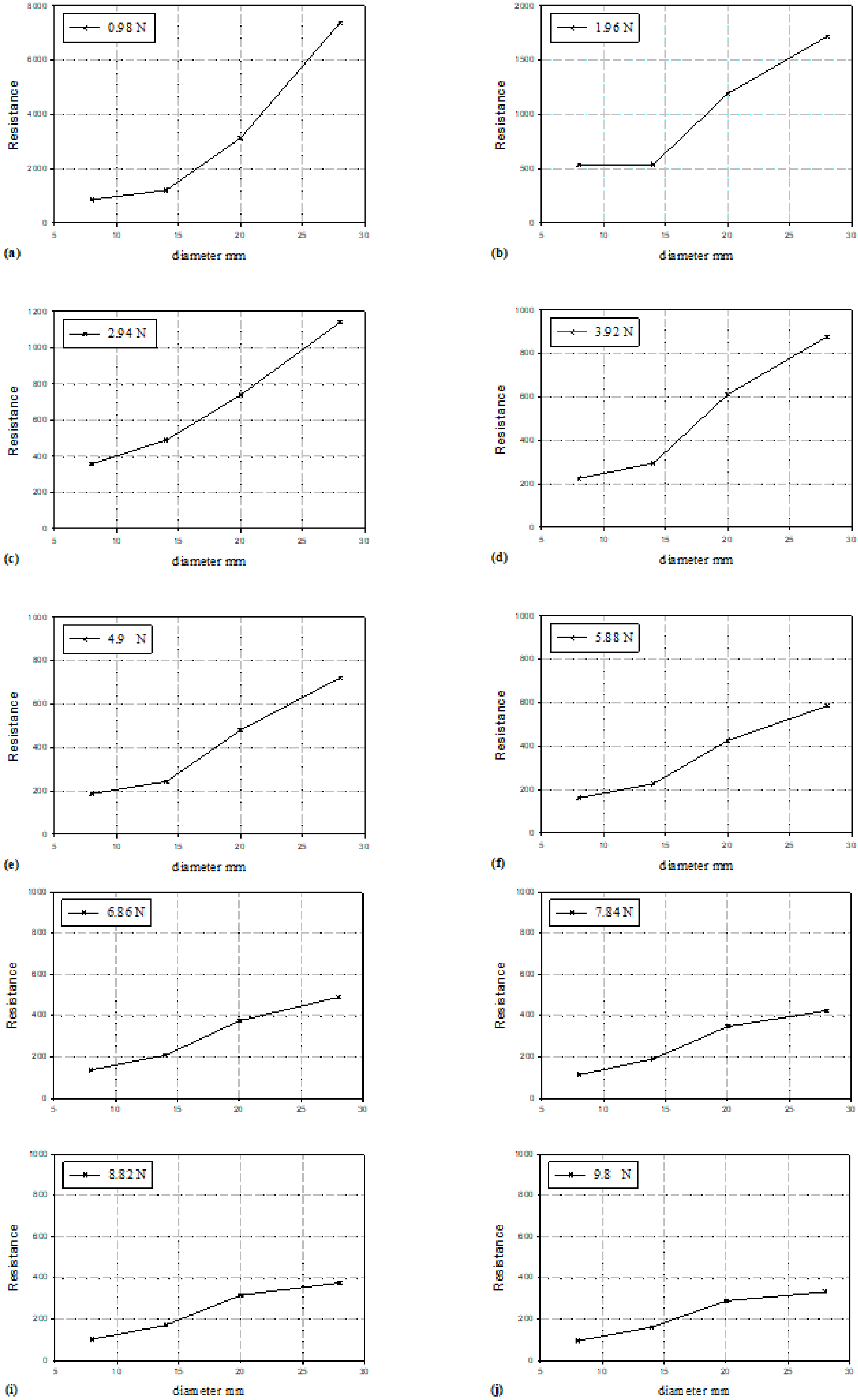


Figure 6. Resistance reading of matrix FSR related to different compression disc diameter and for specific load. (a)0.98 N. (b)1.96 N. (c)2.94 N. (d)3.92 N. (e)4.9 N. (f)5.88 N. (g)6.86 N. (h) 7.84 N. (i)7.82 N. (j)9.8 N

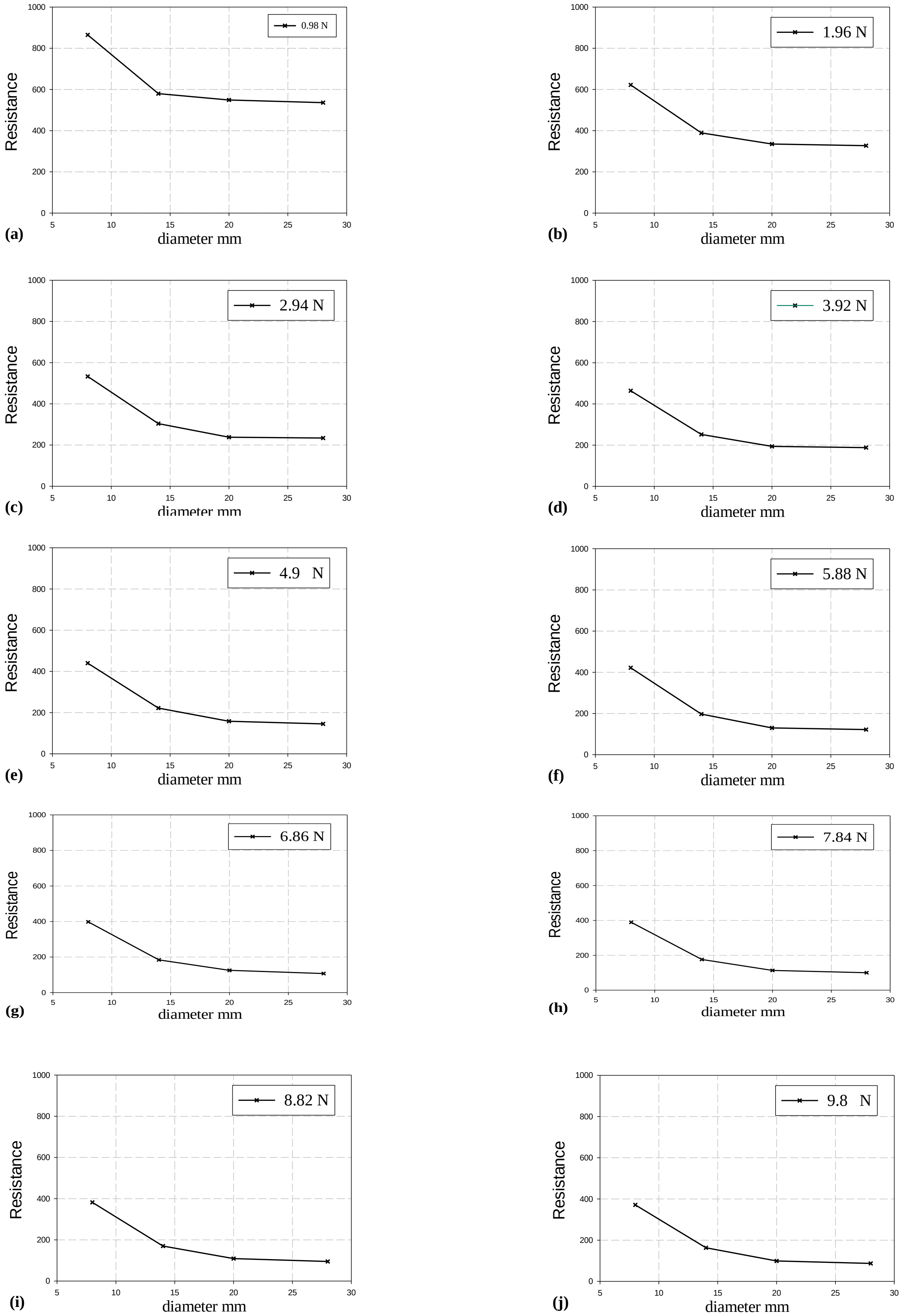


Figure 7. Resistance reading of single output FSR related to different compression disc diameter and for specific load. (a)0.98 N. (b)1.96 N. (c)2.94 N. (d)3.92 N. (e)4.9 N. (f)5.88 N. (g)6.86 N. (h) 7.84 N. (i)7.82 N. (j)9.8 N.

In the other hand, curves in Figure 5 which represent the behaviour of multioutput matrix sensor for different size of compression disc, the maximum resistance that has been recorded was (7387Ω) for the lowest applying load as in Figure 5a, which represent the reading of the sensor using compression disc with (28 mm) in diameter, while the lowest resistance value was (95Ω) for the highest applying loud as in Figure 5d, which represent the reading of the sensor using compression disc with (28 mm) in diameter. In order to understand the effect of the contact area on the reading of the single output sensor and the matrix sensor. Better understanding for the effect of the contact area on the reading of each design of sensor has been gotten through the Figure 6 and 7. Regarding to the single output sensor design, if a specific applying load has been taken and comparing the resistance of the sensor for different compression disc, it has been found that, as long as the contact area has been increased, the resistance of the sensor will be decreased as shown in Figure 8a. Opposite to that, if any certain applying load has been chosen and comparing the values of the resistances regarding to the four different compression discs, it has been found that the resistance of the sensor will be increased as the contact area increased as shown in Figure 8b.

These two opposite behaviours can be explained by understanding how does the contact area affect on the applying load and the conductivity of the Velostat. Regarding to the effect of the contact area on the applying load, it is for granted that as the area increase, the pressure will be decrease because the force will be distributed on larger area according to the equation:

$$Prssure = \frac{Force}{Area}$$

This equation gives a good explanation for the behaviour of the matrix sensor's design where it has a 16 *16 sensing elements and despite of the increasing in contact area between the applying load and the sensor, the area of the active sensing element still constant which depends on the thickness of the electrode lines as shown in Figure 10(a). Thus, the increase in the contact area will be accompanied by decreasing the load that has been applied for each sensing elements which will lead to decrease the conductivity and increase the resistance of the Velostat that lies between each element.

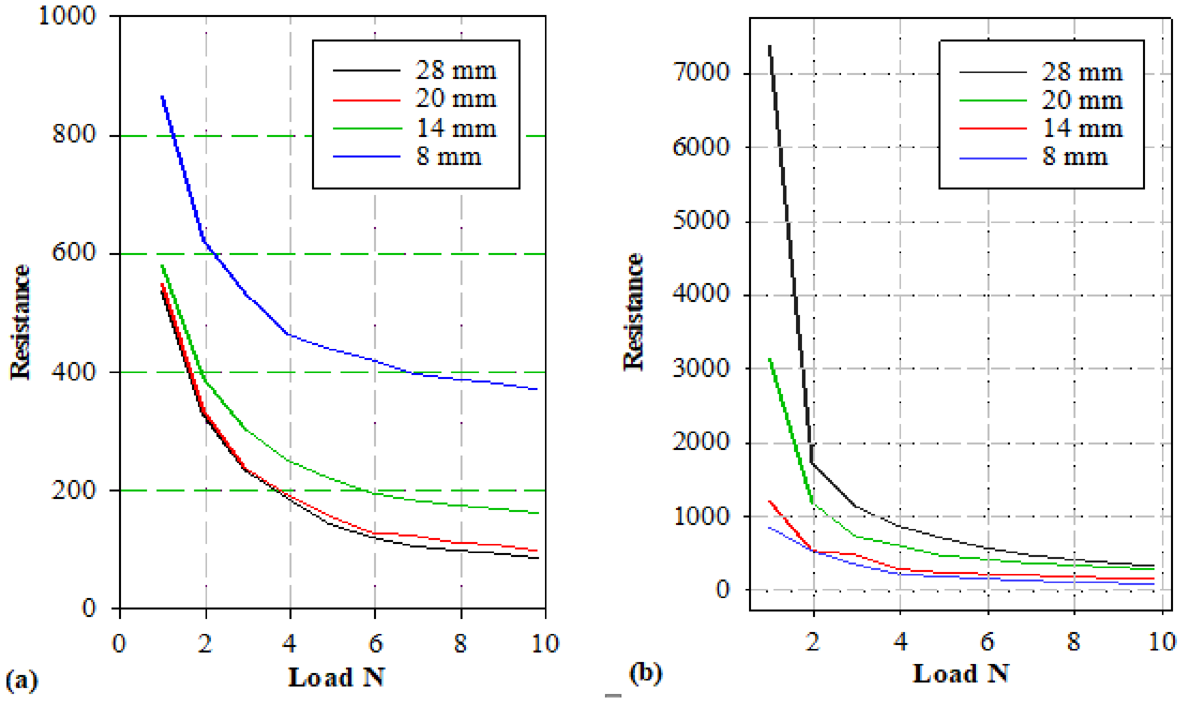


Figure 8. (a) The resistance of single output sensor during static load test for four different diameter of compression disc. (b) The resistance of matrix sensor during static load test for four different diameter of compression disc

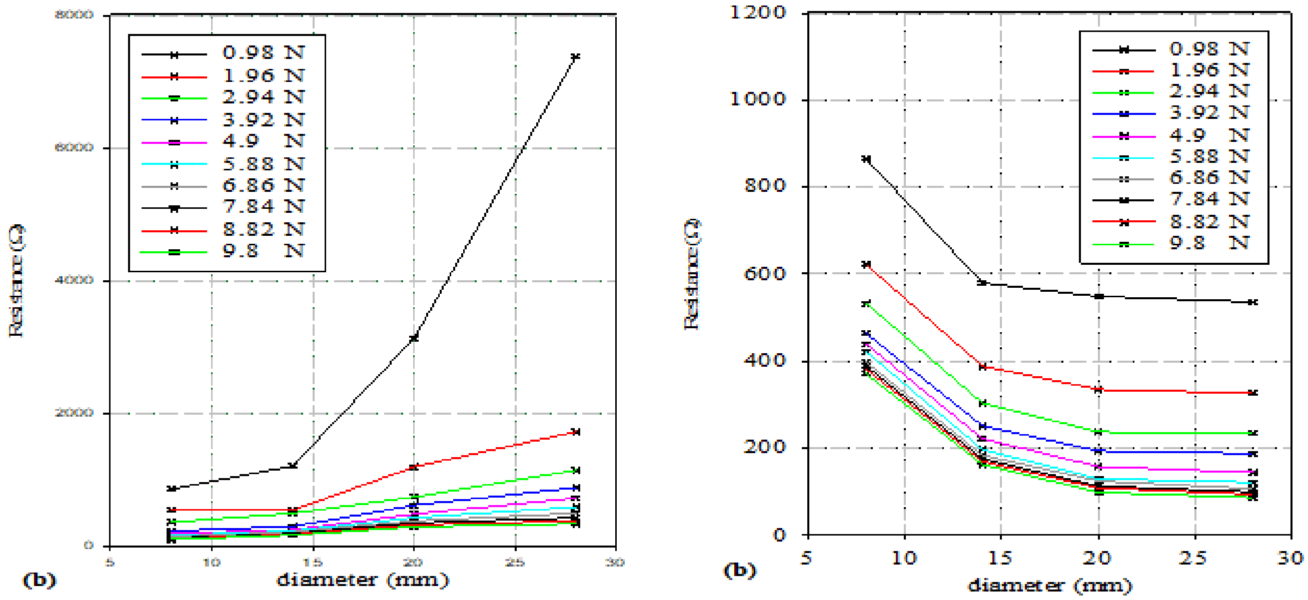


Figure 9. (a) Effect of the contact area on the resistance reading of single output sensor design. (b) Effect of the contact area on the resistance reading of matrix sensor design

For single sensor design, the increasing the contact area will also cause distribution of the force over larger area, but instead of increasing the resistance, the resistance will be decrease. Percolation phenomenon has a good explanation for this behaviour. As load applied to the Velostat, direct conductive path can be generated and lead to an increase in the conductivity with decrease in the resistivity of the material and as well as the contact area increase, a new conductive path will be generated an added to the previous paths as shown in **Figure 10(b)**. The new paths work as resistances that connects in parallel which leads to decrease the equivalent resistance of the sensor according to the law of the equivalent resistance of parallel resistances.

$$\frac{1}{Req} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \;\; ....$$

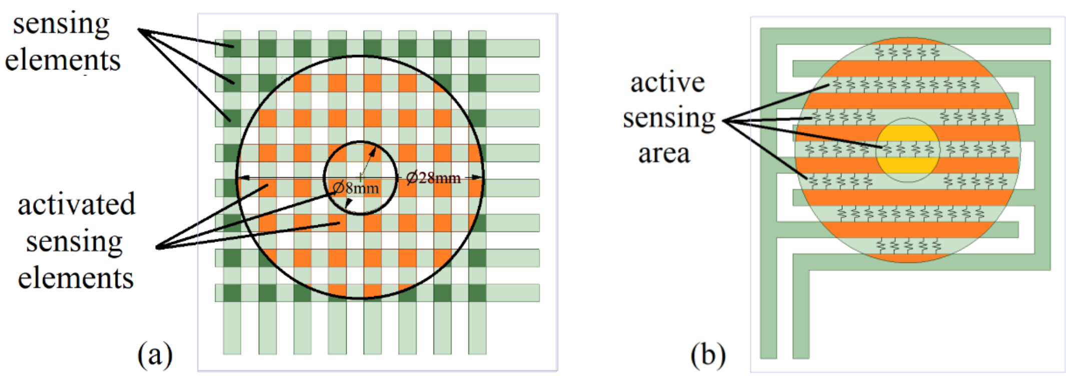


Figure 10. (a) applying two different compression disc size on the single output sensor. (b) Applying two different compression disc size on the multioutput matrix sensor.

4. Conclusions

In this work, the behaviour of single output flexible force sensor design and multioutput matrix force sensor design have been studied by applying different static loads using different contact area between the load and the sensor. It has been found that the area of contact has a great effect on the reading of the sensor specially for load lower than 2 N. The two designs of the force sensor behave oppositely, where the increasing of the contact area cause a decrease in the resistance reading of the single output sensor for the same static load, while the increasing of the contact area cause an increase in the resistance reading of the single output sensor for the same static load. For the single output it is impossible to overcome this effect but for the matrix sensor it is still possible to reduce this effect through the ability of calculating the area of the applying load by calculation the activated sensing elements during the loading phase and study the relation between the activated sensing element and the reading of the sensor as a future work.

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