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SENSOR ELEMENTS MADE OF CONDUCTIVE SILICONE RUBBER FOR A COMPLIANT GRIPPER

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ABSTRACT

The purpose of this paper is to create the foundation for the use of conductive silicone rubber (Powersil 466 A/B VP) [1] as sensor elements. Therefore, several investigations of the characteristics of conductive silicone rubber are carried out depending on different loads. The sensor element made of conductive silicone rubber changes its electrical properties under the influence of the loads. This paper presents an application of this material as sensor elements for a new compliant gripper. The sensor elements of the gripper have two functions; they are parts of the gripper structure and they give rough information about the gripping process. The production technology of the sensorized gripper and the experimental measurements are discussed in this paper.

Index Terms - Sensor, compliant, gripper, silicone rubber, electrically conductive

1. INTRODUCTION

Conductive silicone rubber composite is made of nonconductive elastomer, to which conductive particles are added [2]. Conductive silicone rubber has the ability to change its electrical resistance under mechanical load, which leads to deformation of the material. These properties make this material suitable to develop force or strain sensors [3, 4].

Sensorized systems are very important in the area of the robot gripper, especially for human-machine interfaces. In [5], a piezoelectric polymer film was used as a contact sensor. The sensor is placed on the finger surface and responds to the changes in the load during the gripping process and the manipulation. Furthermore the noncontact-contact transition will be identified. In [6], a new commercial sensor adapted to detect slippage is presented. Reference [7] shows an application of a biomimetic tactile sensor for grasping exercises.

This paper presents an application of conductive silicone rubber as sensor elements which are to be embedded in the gripper structure. The sensor elements should be able to determine rough information about the gripping process.

2. STUDY ON THE CHARACTERISTICS OF AN ELECTRICALLY CONDUCTIVE SILICONE RUBBER

The electro-mechanical characteristics of conductive silicone rubber can be influenced by different factors. Some factors are undesirable because of their negative or parasitic effect on the setting and the behavior of the electrical resistance of a specimen. Therefore, many factors during the production of the specimen, such as environmental conditions (temperature, humidity), the means of connection of the specimen to the voltage source etc., may affect the setting of the initial resistance of the specimen. Also when a specific mechanical load is applied during the experimental investigations of the specimens, other factors such as temperature changes can give incorrect results for the resistance. However, a specific executed mechanical load has to demonstrably change the resistance of the specimen to obtain sensory properties. The desirable and undesirable factors which lead to changes in the electrical resistance of the specimen are shown in Figure 1. The influence of negative factors should be kept as small as possible in the production and in the experimental investigations.

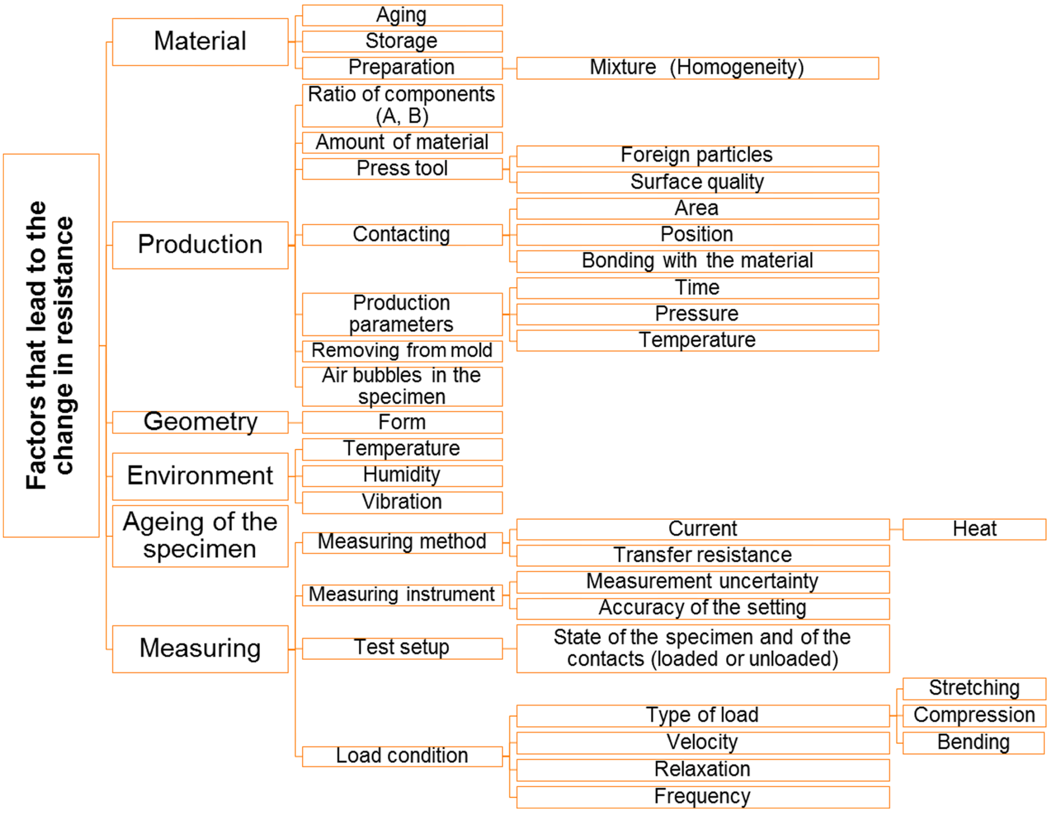


Figure 1. Factors that lead to the change in the electrical resistance

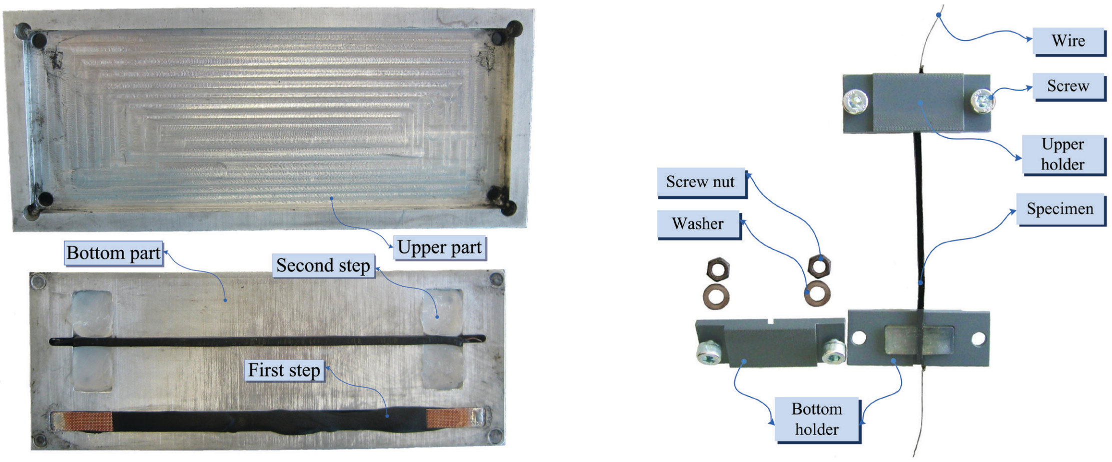
The main point of this paper is the experimental investigation of the electro-mechanical characteristics of electrically conductive silicone rubber. The behavior of the electrical resistance of the specimen is characterized in dependence on the strain, which is recorded during tensile and compression loads. The measurements were executed with the help of the Zwick ProLine material testing machine in the laboratory of Mechanism Technology Group, Department of Mechanical Engineering at Technische Universität Ilmenau in Germany.

2.1 Investigation of the characteristics of the electrically conductive silicone rubber in dependence on tensile load

With the purpose of spotting the conditions for preconditioning and the work area of electrically conductive silicone rubber (Powersil 466 A/B VP), several tests were carried out for many sensor specimens at two different velocities.

2.1.1 Production of the sensor specimens

The material which the specimens are made of will be used for press molding. The specimen contains five parts. The first part is made of an electrically conductive silicone rubber (Powersil 466 A/B VP Shore Hardness A 37) and it has dimensions of 100 × 2 × 5 mm^3. The nonconductive silicone rubber (Elastosil ® R 420 Shore Hardness A 70 MH C1) is used for the other parts. The dimensions of each part are 10 × 11.5 × 5 mm^3. The five parts are connected using a special technology, namely, the prefabricated conductive silicone rubber part is pressed together with the raw nonconductive silicone rubber parts, i.e., the production process consists of two steps.



(a) (b)

Figure 2. a) Press tool; b) Holder

The press tool is designed to produce a specimen with the help of the hot press machine (Figure 2a). The design of this press tool enables it to produce the specimen in two steps. In the first step, the part made of conductive silicone rubber is pressed with the available Cu-wire netting attached to both ends of this part, and then in the second step, the prefabricated conductive silicone rubber part is pressed again with the raw non-conductive silicone rubber, where the other four parts are created. The Cu-wire netting is placed between them accordingly. Because of the nonconductive silicone rubber, these four parts cannot distort the electrical resistance of the specimen. And they enable the use of a special holder for the specimen during the tensile tests (Figure 2b); thereby the specimen is not affected by any other loads, such as the mechanical compressive forces. Hence, none of the contact elements (Cu-wire netting) is influenced by anything during the tensile test.

2.1.2 Tensile tests for sensor specimens made of Powersil 466 A/B VP

Several tensile tests were conducted, varying the velocity to determine the curve of the electrical resistance of the conductive silicone rubber.

The results of these experiments show that the sensor elements can be stretched by at least 100%, during which the resistance continuously increases. The curves are close to each other from the second cycle. In addition, the velocity influences the run of the resistance curve. The higher the velocity is, the more noticeable is the change in the resistance and in the hysteresis (Figure 3). However, the resistance becomes smaller after several cycles. Furthermore, it is found that a residual deformation is produced after several loads, which must be avoided in order to obtain a signal only from the change in the resistance. Consequently, the sensor elements are to be installed in a system in a pre-loaded situation.

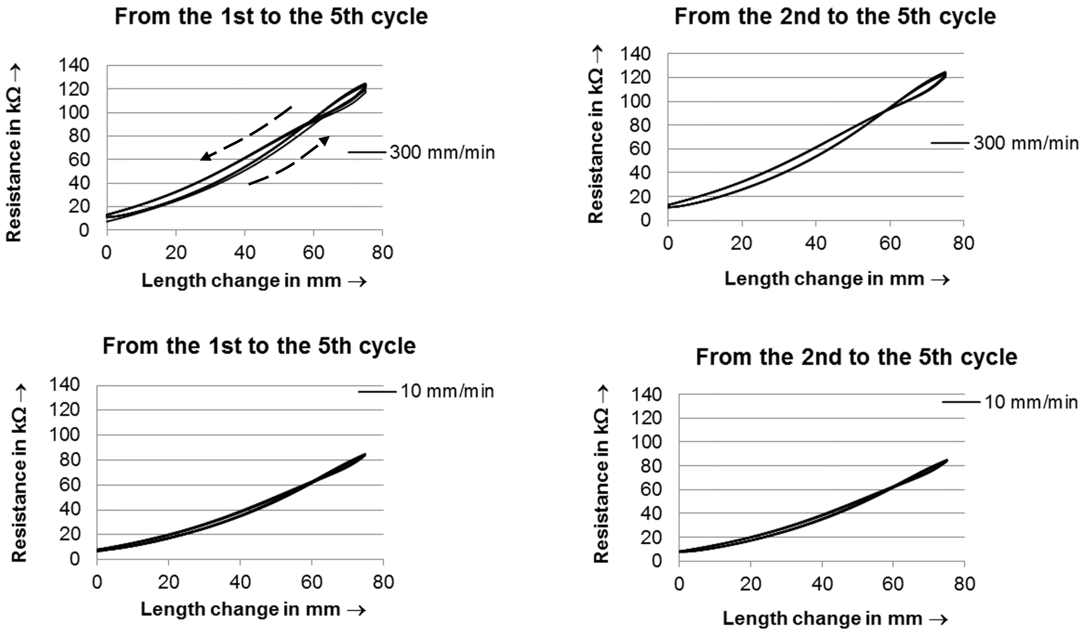


Figure 3. Uniaxial tensile test of sensor specimen made of Powersil 466 A/B VP, pre-load: 1,3 N, strain: 100 %, unload: 0 %, waiting time: 10 s, number of cycles: 5

Moreover, the resistance was measured at a constant strain to determine the dependence of the resistance on the time (Figure 4). The test was carried out as follows: a setting cycle with strain of 100% followed by a measurement phase, which consists of loading until the strain reaches a value of 100%, after which there is a holding time of 15 h and then unloading until the strain is equal to 0%. The test velocity was 10 mm/min.

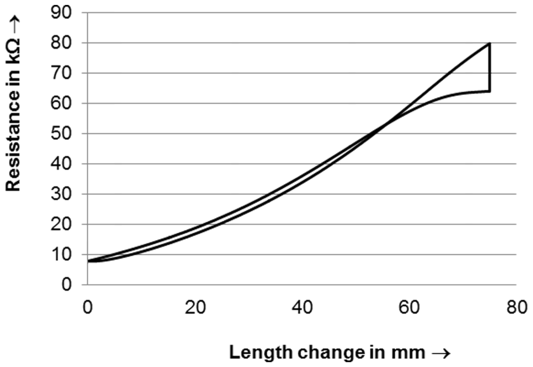


Figure 4. Dependence of resistance on time with the relaxation of the sensor specimen

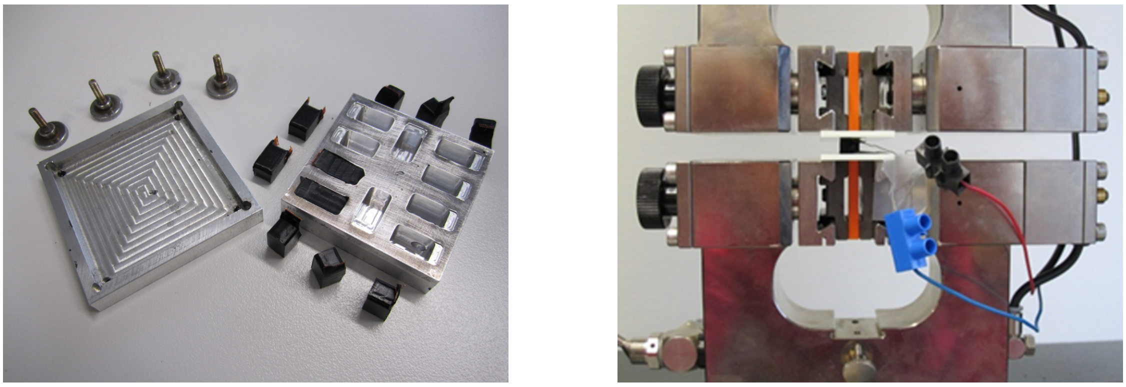
The result of this experiment is that the electrical resistance decreases at a constant strain. Thus, this behavior reflects the stress relaxation of the viscoelastic materials (polymers). The stress relaxation is due to the diffusion processes in the microstructure, which in turn could affect the electrical resistance.

2.2 Investigation of the characteristics of the electrically conductive silicone rubber in dependence on compression load

A number of experiments were conducted on several sensor specimens at two different velocities to determine the behavior of the material under compression load.

2.2.1 Production of the sensor specimens

A press tool made of aluminum was used for production of the sensor specimens (see [4]). The sensor specimen is 9 mm thick, 9 mm wide and 15 mm long (Figure 5).



(a) (b)

Figure 5. a) Sensor specimens with the press tool; b) Test setup

2.2.2 Compression tests for sensor specimens made of Powersil 466 A/B VP

The electrical resistance of Powersil 466 A/B VP increases under the compression load. The following test shows the behavior of this material under mechanical stress (Figure 6).

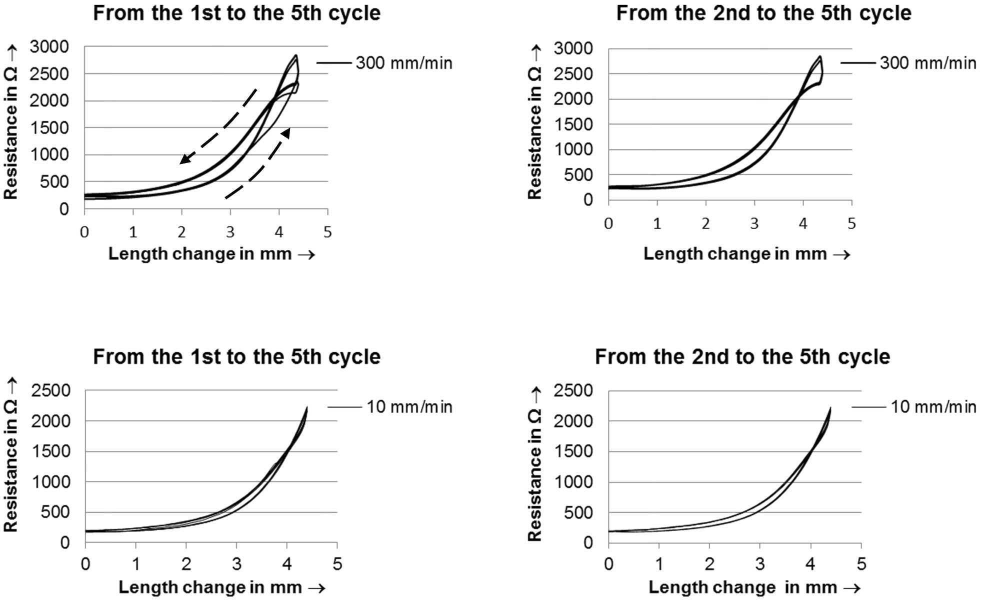
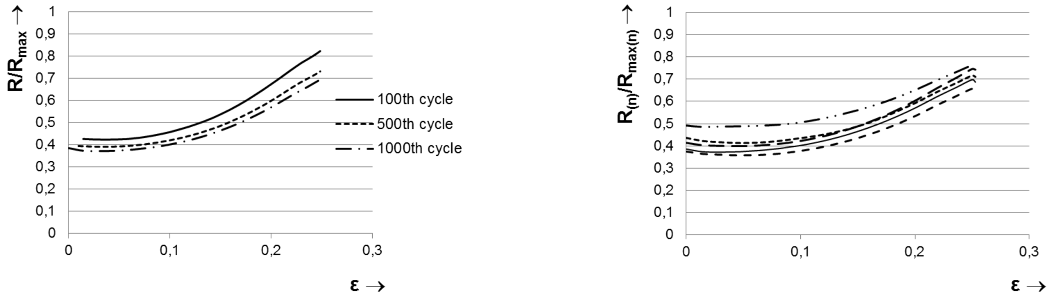


Figure 6. Uniaxial compression test of sensor specimen made of Powersil 466 A/B VP, pre-load: 10 N, compression: 50%, unload: 0%, waiting time: 10 s, number of cycles: 5

The curves show that the first two cycles differ from other cycles, i.e. an approximately constant behavior of the material is achieved after at least three load cycles. Hence, it is recommended to load the sensor element over at least three cycles so as to achieve a preconditioning. Moreover, the change in the resistance and the hysteresis at low velocity are smaller than at higher velocity. The sensor specimen becomes flatter after several cycles, which can lead to an incorrect signal and undesirable idle state in an application. For this reason, a pre-load was used and is recommended for the applications.
A cyclic loading was performed for five different specimens with a maximum strain of 25% (Figure 7).



(a) (b)

Figure 7. Cyclic loading, pre-load: 3.5 N, strain: 25%, unload: 0%, testing velocity: 300 mm/min, number of cycles: 1000. (a) Different cycles for a sensor element; (b) The 1000th cycle for 5 different sensor elements

Figure 7a shows that the resistance is getting smaller after several cycles. In Figure 7b, the resistance curves for five different sensor specimens during the 1000th cycle are illustrated.

3. APPLICATION OF POWERSIL 466 A/B AS SENSOR ELEMENTS IN A COMPLIANT GRIPPER

A compliant gripper (Figure 8) was designed at the University of Nis in Serbia (see [8]). The main point of this paper is to discuss the sensor integration in this gripper.

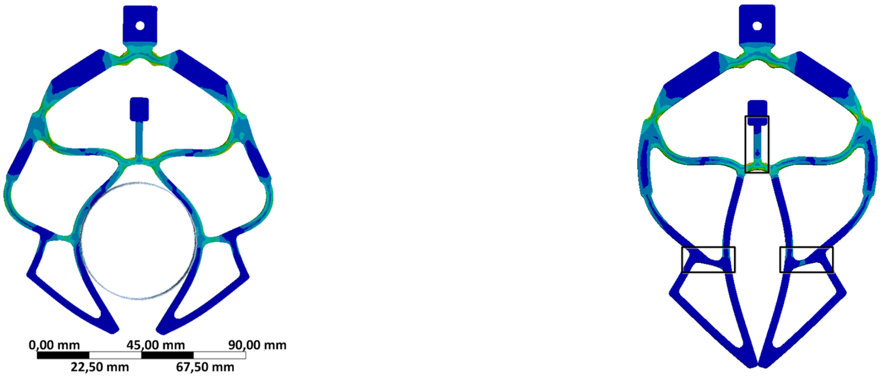
Figure 8. Compliant gripper without sensor elements from [8]

3.1 Design and manufacturing process of the sensor elements

The sensor elements can be assembled into the gripper in the contact area with the object (as an external component), or they may be embedded in the gripper structure. In this paper, only the embedded sensor elements are considered. The benefit in this case is that the embedded sensor elements are parts of the structure, in addition to providing their sensing capability.

This multifunctionality allows for compact design and increases the flexibility of a compliant system.

The first step of the design process is to determine the proper positions of the sensor elements in the gripper structure. These positions are recognized by the maximum change of the mechanical stress under the load generated during gripping. This load will cause a deformation, which in turn induces a change in the electrical resistance of the sensor elements. Therefore, FEM (Finite Element Method) simulations are used to determine the appropriate locations (Figure 9).

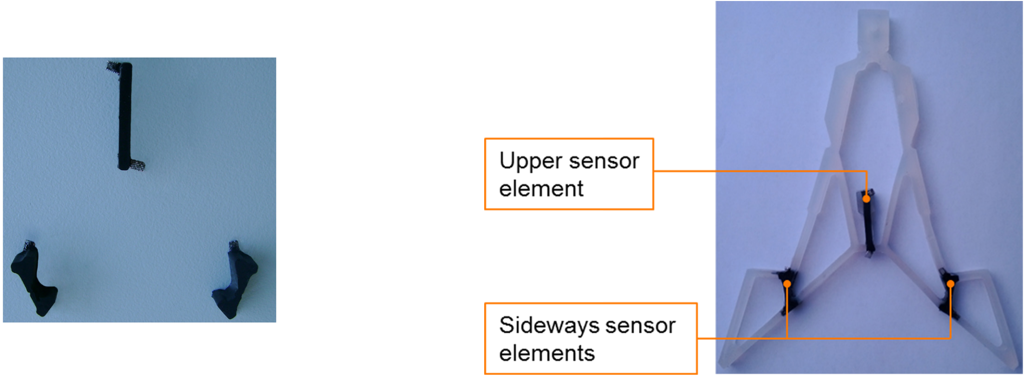


(a) (b)

Figure 9. Simulated gripper with the stress distribution during grasping: a) with object; b) without object

According to the simulation results, the positions shown in Figure 9b are suitable as sensor elements, because the stress difference between the grasping with and without an object is greatest here. In addition, another location is selected where only tensile load acts (Figure 9b). These areas should be made of conductive silicone rubber and embedded in the gripper structure.

The technology explained in section 2.1.1 was used for manufacturing the compliant sensorized gripper. The manufacturing consists of two steps. In the first step, only the sensor elements which will be made of conductive silicone rubber were hot pressed in a pressing tool. In the second step, the sensor elements produced were placed in their planned positions in the cavity of the gripping structure in the pressing tool. The remaining empty places in the gripper structure were filled with nonconductive silicone rubber and then all parts of the gripper were vulcanized together (Figure 10).

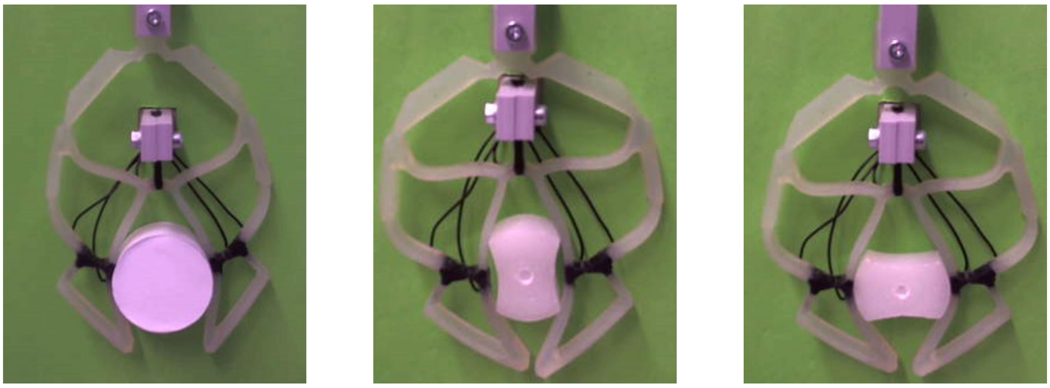


(a) (b)

Figure 10. a) Sensor elements after the first manufacturing step; b) Sensorized compliant gripper after the second manufacturing step

3.2 Experimental results

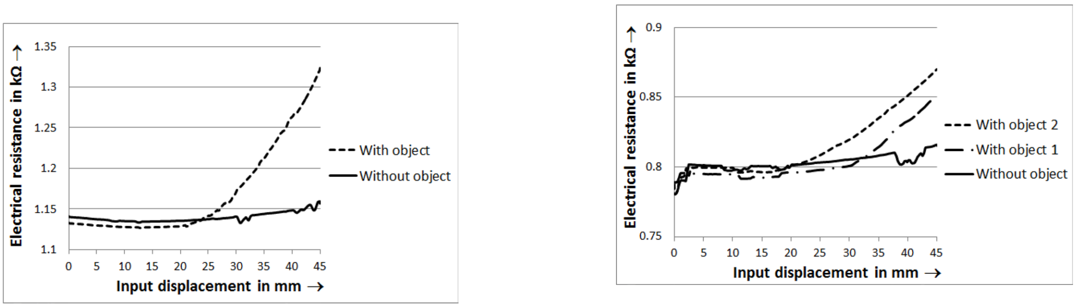
The measurements on the sensor elements during the gripping process were conducted with the help of the Zwick ProLine material testing machine in the laboratory of Mechanism Technology Group, Department of Mechanical Engineering at Technische Universität Ilmenau in Germany. The following results were obtained using only one of the two sideways sensor elements. The upper sensor element was not considered here, since the measurement results of the three sensor elements have a qualitatively similar character.



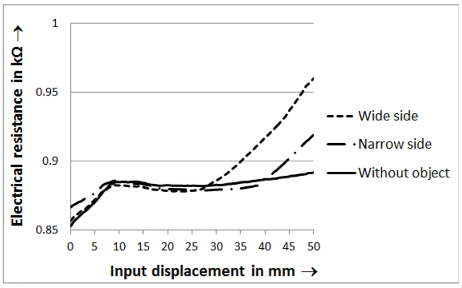
(a) (b) (c)

Figure 11. Grasping of different objects: a) round object; b), c) objects with sides of different lengths

The test parameters used for the gripper actuation are as follows: The input displacement is between 45 and 50 mm and the speed of the movement is 300 mm/min. Different objects were used for these experiments (Figure 11).



(a) (b)



(c)

Figure 12. Detecting
a) the presence of the object;
b) its size;
c) the orientation of the object in the gripper

According to the measurement results, the sensor elements can detect the presence of an object. Furthermore, objects with different diameters (42 mm and 35 mm) such as in

Figure 11a can be differentiated. In addition, the orientation in the gripper of objects whose side lengths are different (Figure 11b, 11c) can also be identified (see Figure 12).

4. CONCLUSION

A sensor element made of Powersil 466 A/B VP Shore Hardness A 37 has a relatively stable electrical behavior under mechanical load. Therefore, the sensor element is used for applications which require only qualitative analysis. An application of Powersil 466 A/B VP as sensor elements in a compliant gripper is described in this paper. The drawbacks of these sensor elements can be found in the electrical connections, which may be responsible for the oscillation of the resistance changing. But this problem is of interest only in the quantitative analysis. Other drawbacks are a complex manufacturing process (at least 4 hours for a gripper) and a high scrap rate during this process (about 50%). The main advantages of this gripper are in their embedded sensor elements, which have two important functions. They are parts of the gripper structure and they provide rough information about the grasped object. The sensor elements can detect the presence of an object, objects of different sizes and the orientation in the gripper of an object whose sides are different lengths.

5. ACKNOWLEDGEMENTS

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