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DESIGN AND APPLICATION OF COMPLIANT MINI-GRIPPERS FOR HANDLING CHEMICALS

In this paper we propose an original configuration of a compliant mini-gripper for handling chemicals. The compliant mini-gripper is 3D modeled and analyzed with finite element method. To use it in a wider range of containers designed for laboratories we made several variants of fasteners. In order to obtain a functional prototype in a scale appropriate to characterize the system, we determined the material properties of the gripper and developed an experimental stand for characterizing the system with mini-gripper. Finally, we compared the movements of the experimental grip, made according to the movement of the bellows type actuator, determined based on, analytical and numerical results.

1. Introduction

The mini and micro compliant grippers are generally single piece structures that provide the desired movement by elastic deformation of flexible couplings. Deformation of flexible joints is reversible and is maintained within the validity of the Hooke's law, approaching more natural structures [8, 12]. Complaint mini-grippers have the advantage of miniaturization, give the possibility to achieve precise movements, and have a compact structure [7]. Due to elastic behavior of the system, makes it returns back to its original position after the load is off, so there is no need for springs to make it possible [6]. Compared to conventional mechanisms, compliant mechanisms are free of friction, have reduced vibration, noise and games, and do not require

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lubrication, which makes them ideal for applications in handling samples of chemicals.

The specialized literature describes different models of grippers for various applications of micromanipulation, in the field of micro-assembling field [1, 4, 13] with piezo actuators [2], MFA [5, 10] and other variants of non-conventional actuators [14].

This paper presents design of a compliant mini gripper configuration for handling objects in chemical environments, describes models, analyzes, and realization of an experimental model. System validation is done on an experimental stand.

2. Design of a gripper for micromanipulation

2.1. 3D modeling of compliant mini-gripper

Firstly, we design a compliant mini-gripper configuration with four identical grip modules shaped for handling chemicals. Each fixture module is designed as a compliant structure with two flexible joints with rectangular connection. The four modules are fixed on a clamping circular mobile platform, driven by a bellows-type element. The 3D compliant mini-gripper model can be seen in Fig. 1.

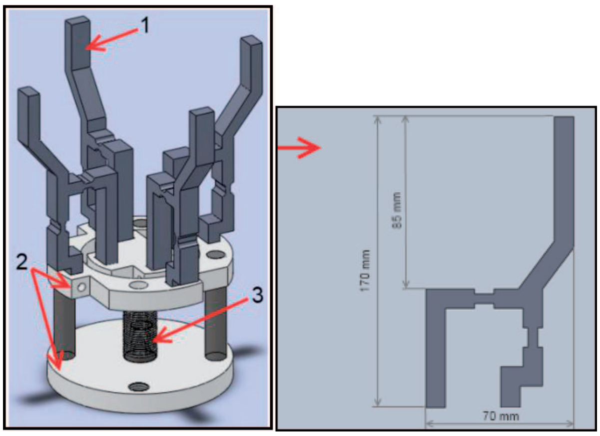


Fig. 1. The compliant mini-gripper

The system is composed of: 1 – elastic joints items, 2 – fixed/support elements, 3 – bellows-type actuator.

2.2. Constructional variants of grippers

The compliant mechanisms proposed in the paper have the advantage of having active elements for interchangeable grip. The fasteners are dimensioned according to the size of containers used in the laboratory for handling chemicals [16, 17].

In Fig. 2 (a, b, c, d), there are suggested some constructional variants of the clamping elements according to the grip handle of the receptacle (Fig. 2e [22]).

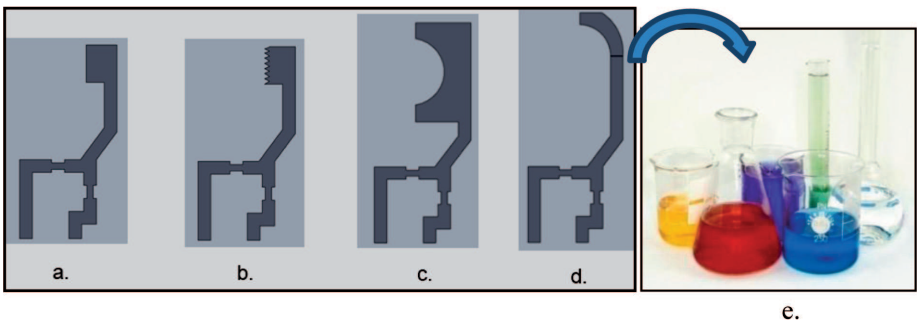


Fig. 2. Clamping modules and laboratory containers

3. Analyses of the designed system

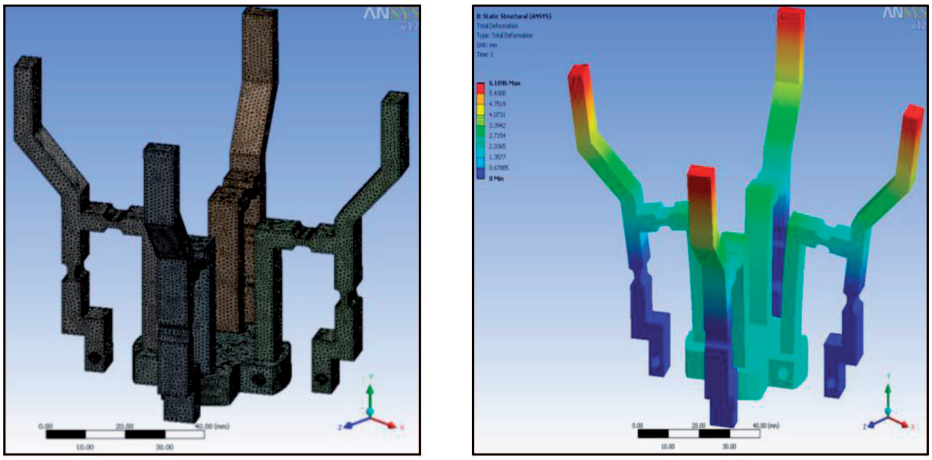
The characterization of the designed system is realized in two ways, using 3D finite element model, and analytical calculation with the Castigliano's theorem.

3.1. The Finite Element Method of analysis

To determine the gripper displacement when it is operated, and perform the numerical calculation, we used the ANSYS program [18]. The CAD model was introduced into the program; also input quantities such as Young's modulus, Poisson's ratio, and pressure of 0.7 MPa etc. In Fig. 3a, we have the discretized element model with finite elements, and in Fig. 3b the maximum displacement of the compliant mini-gripper [3].

For the mini-gripper shown above, we considered a total of 167.550 structure elements and the number of nodes 300.016. After finite element analysis, the following results were obtained:

– maximum displacement of active elements: 6.10 mm;
– maximum stress in the structure: 35.21 MPa.



a. b.

Fig. 3. Discretization and total displacement of the mini-gripper elements

3.2. Analytical calculation of active elements of the compliant mechanism

For determining the displacement of the mechanism, we need to know what type of flexible joints should be used. Important data for determining the joint displacements are: joint length (l_f), the length of active elements (l_1), joint section (A), the moment of inertia (I), joint height (t), joint thickness (b), and the modulus of elasticity (E) [9]. In Fig. 4, we can see several sizes of flexible joints determined according to their compliance.

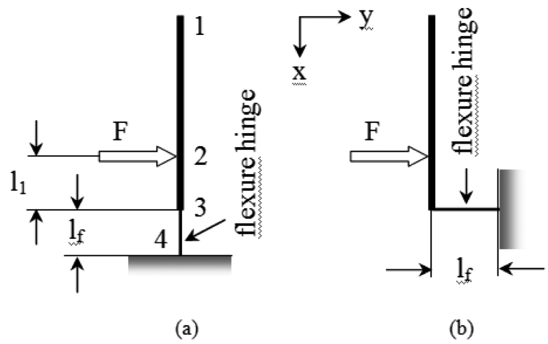


Fig. 4. Lever-based displacement amplification with flexure hinge: (a) flexure parallel to lever; (b) flexure perpendicular to lever

To determine movement of the active elements of the mechanism with rectangular cross section, such as that used in the paper, we used the Castigliano's theorem with the relation:

$$U = \frac{F\left(I + Al_1^2\right) l_f}{EAI} \tag{1}$$

$$I = \frac{bt^3}{12} \tag{2}$$

where: $A = 10$ mm^2, $E = 1811$ MPa, $l_1 = 50$ mm, $l_f = 5$ mm, $I = 6.66$ mm.

After entering the data into the formula, and applying the pressure of (2...7 bar), we obtained the results presented in Table 1.

Table 1.

The analytical results of displacement

The pressure in the bellows (bar)	*Displacement (mm)*
2	2.07
3	3.10
4	4.41
5	5.18
6	6.21
7	7.25

4. Practical realization of the compliant mini-gripper

The mini-gripper structure was made using the cutter type ISEL CPM 2018. The elements were cut from 8 mm thick polycarbonate material. We used a 2 mm milling tool with 3000 rot/min cutting speed, feed rate of 5 mm/sec, and cutting deepening of 1 mm [15, 20, 21].

The images in Fig. 5 show the physically realized mini-gripper, after cutting and mounting the control elements.

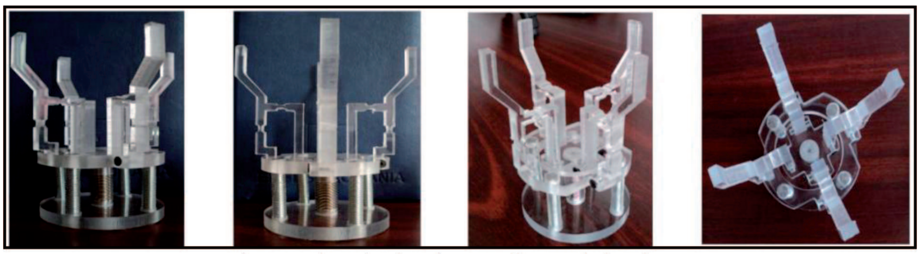


Fig. 5. The obtained compliant mini-gripper

Functioning of this compliant mechanism is simple. In Fig. 6, the compliant gripper can be seen functioning with air pressures of 0, 3 and 7 bar.

The air is introduced into a sylphon and this produces movement of the compliant mechanism. In the case 1, the system pressure is 0 bar, so the sylphon is in an initial state. In the case 2, when pressure increases to 3 bar, the sylphon lengthens and puts in motion elastic elements of the mechanism. In the case 3, the maximum 7 bar pressure the sylphon can hold is applied, and this produces a maximum displacement transmitted to the final elements of the mechanism (colored in black).

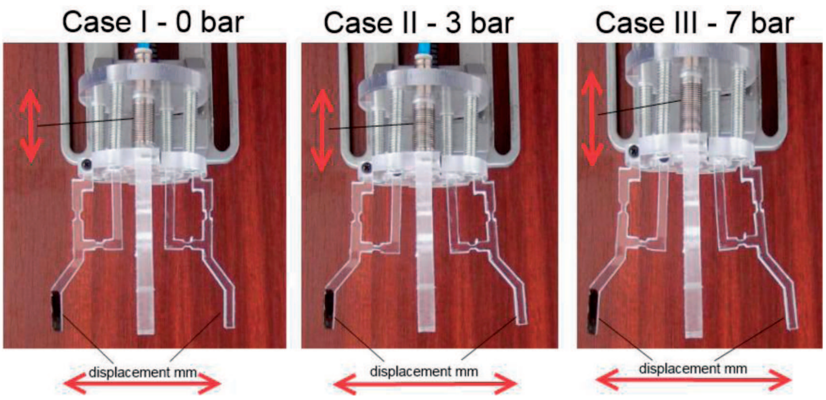


Fig. 6. The functioning compliant mini-gripper

5. Experimental results

5.1. Bellows testing

For experimental determination of displacement of the bellows-type flexible tube actuator, we used the bench shown in Fig. 7.

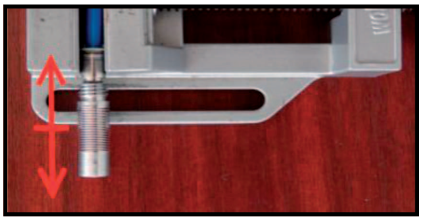


Fig. 7. The stand for determining bellows displacement

Determination of displacement was realized by taking pictures and using the program VEDDAC 6. The values of displacement related to the applied bellows pressures are listed in Table 2.

Table 2.

Results of experimental measurements bellows

Test Nr.	*The pressure in the bellows (bar)*	*Displacement (mm)*
1	2	1.25
2	3	1.75
3	4	2
4	5	2.32
5	6	2.5
6	7	3

5.2. Determining the material for the mechanical modules

To realize the functional prototype scaled-up to characterize the system, we determined the properties of the material of which the gripper was made, respectively the Young's modulus and the Poisson's ratio, with the stand shown in Fig. 8.

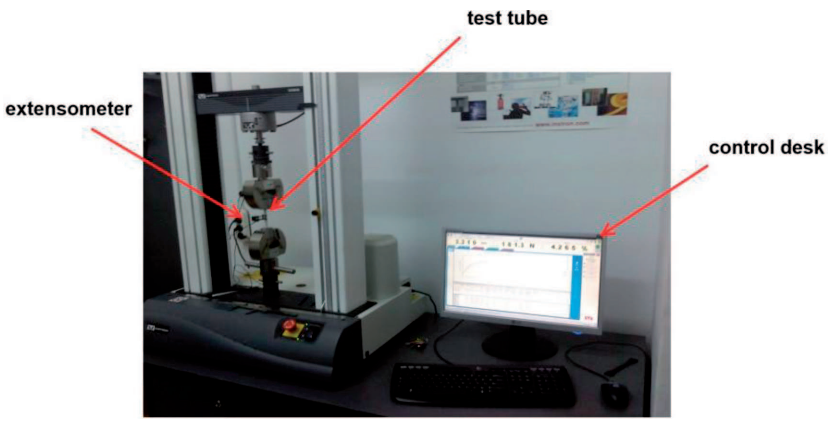


Fig. 8. The measurement stand

In the following experiments, we determined the material properties using the INSTRON machinery [19], an extensometer for measuring deformation of parts under tension, and three identical specimens of polycarbonate. The graph of part deformation during testing, the stretch resistance up to the maximum tensile load, can be seen in Fig. 9. Among the results provided by the Instron universal testing machine, which can be seen in Table 3, the interesting ones were the values of the Poisson's ratio, 0.39, and the Young's modulus, 1920 MPa (after linearization of data).

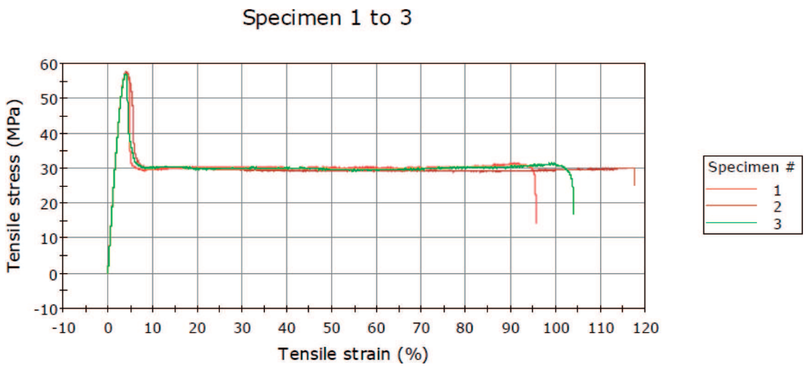


Fig. 9. The graph of specimens deformations

Table 3.

The results of examinations of the material

	Comment	Maximum Load (N)	Tensile strain at Tensile Strength (mm/mm)	Tensile stress at Tensile Strength (MPa)	Tensile strain at Break (Standard) (%)	Modulus (E-modulus) (MPa)	Tensile stress at Yield (Offset 0.2 %) (MPa)
1	10x7.7	4,413.64	0.03841	56.81267	95.77	1,809.47	48.53
2	10x7.7	4,436.87	0.04151	57.55765	117.64	1,815.89	48.98
3	10x7.7	4,386.90	0.03821	56.67148	104.02	1,806.27	48.65
Maximum		4,436.87	0.04151	57.55765	117.64	1,815.89	48.98
Mean		4,412.47	0.03938	57.01393	105.81	1,810.54	48.72
Minimum		4,386.90	0.03821	56.67148	95.77	1,806.27	48.53
Standard Deviation		25.00674	0.00185	0.47614	11.04365	4.89938	0.23518

5.3. Realization of the experimental stand for characterization of the system

The experimental stand for characterization of the mini-gripper system is shown in Fig. 10.

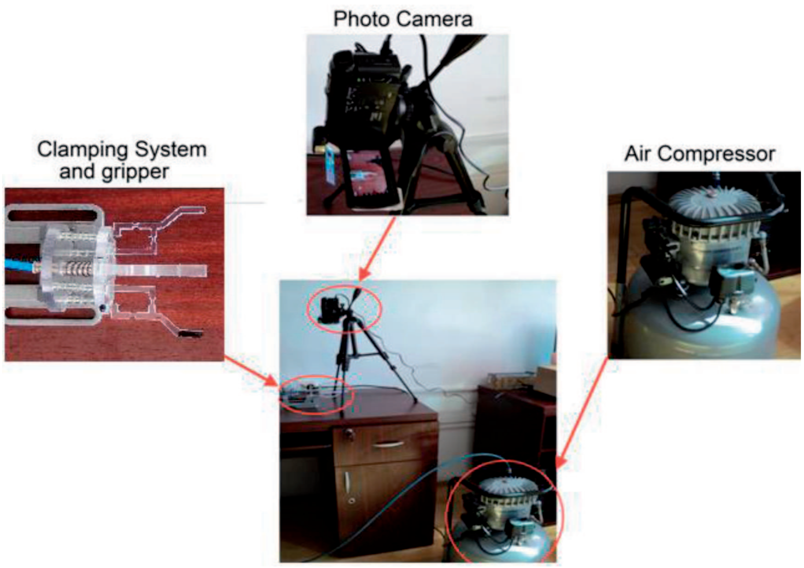


Fig. 10. The experimental stand for mini-gripper testing

The experimental results

The examination of the gripper was performed using the bellows which existed in the structure, and applying air pressures between 2 and 7 bar.

The results of tests on the chassis shown above were obtained with an optical method, by capturing the images of elements. We used a camera that registered one frame for every movement of the active elements of the gripper.

We used the VEDDAC 6 program to determine the displacements based on retrieved images. By counting the pixels in the image, the program can measure the distance between two or more pictures of the same structure. In Fig. 11, we can see the results obtained with the help of this program.

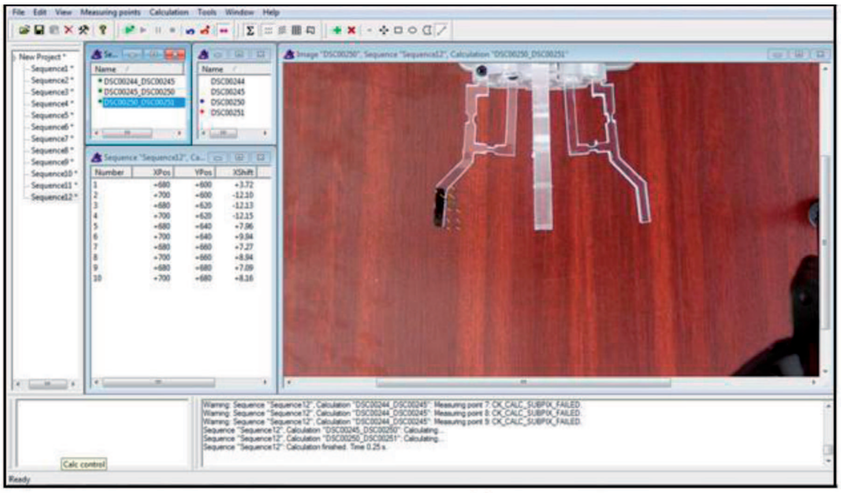


Fig. 11. Results produced by program VEDDAC

The movement corresponding to the maximum opening of the mini-gripper at a pressure of 7 bar in the bellows, was determined to be 8.25 mm, and Table 4 shows other results, according to different pressures introduced into the bellows.

Table 4.

The results of experimental measurements

Test Nr.	*The pressure in the bellows (bar)*	*The maximum displacement (mm)*
1	2	2.5
2	3	3.5
3	4	6
4	5	6.5
5	6	7.25
6	7	8.25

6. Comparison of the results

After analyzing the results of numerical, analytical and experimental investigations of the studied compliant mini-grippers, we found small discrepancies between the results, as shown in Fig. 12.

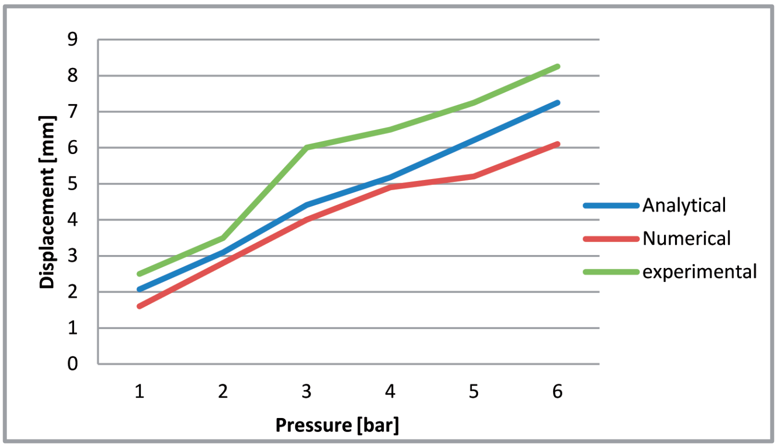


Fig. 12. The graph of research results

7. Conclusions

The compliant mini-gripper for manipulating the chemical samples, proposed in this paper, has the advantage of performing a better controlled movement, due to flexible joints which eliminate some inconveniences that appear in conventional structures. Unlike the classical ones, the compliant mini-gripper has also other advantages: there is no friction in the joint, there is no need for lubrication, no hysteresis can be found, the gripper can be compacted, miniaturized, easy to manufacture and easy to maintain. Yet another advantage it offers is that it can be used in special environments, thanks to chemical resistance of the material from which it is made.

In future we will test the mini-gripper clamping force, and we intend to make a stand to simulate the gripper's work in the laboratory.

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Projektowanie i zastosowanie podatnych minichwytaków do przenoszenia chemikaliów

S t r e s z c z e n i e

W artykule zaproponowano oryginalną konfigurację podatnego minichwytaka do przenoszenia próbek chemikaliów. Opracowano trójwymiarowy model chwytaka i zanalizowano go metodą elementów skończonych. Wykonano kilka wariantów uchwytów dostosowanych do różnych rodzajów pojemników używanych w laboratorium. By otrzymać model funkcjonalny w odpowiedniej skali do charakteryzacji systemu wyznaczono właściwości materiałów chwytaka i zbudowano stanowisko doświadczalne do badań systemu z chwytakiem. Na koniec porównano ruchy eksperymentalnego uchwytu, sterowane ruchem siłownika typu mieszkowego, które wyznaczono na podstawie wyników badań eksperymentalnych i numerycznych.