Journal of Materials and Electronic Devices 3 (2024) 30-36

FYTRONIX
JOURNAL OF
MATERIALS AND ELECTRONIC DEVICES
JMED
http://dergi-fytronix.com/

Topology Optimization for Flexible Robotic Gripper Using Ansys

Kusay DIB [1,*], Muhammet AYDIN[2], Yusuf COŞKUN[3]

[1]Firat University, Faculty of Engineering, Department of Mechatronics Engineering, Elazig, Turkiye
[2]Firat University, Faculty of Engineering, Department of Mechatronics Engineering, Elazig, Turkiye
[3]Istanbul Health and Technology University, Faculty of Engineering and Natural Sciences, Department of Mechatronics Engineering, Istanbul, Turkiye

This study investigates the application of topology optimization techniques to enhance the structural design of a flexible robot gripper, with a specific focus on utilizing PLA (Polylactic Acid) material. Through iterative processes of static analysis and topology optimization, the primary objective is to develop a gripper design that strikes a balance between lightweight construction and structural robustness. The research employs SolidWorks for model creation and Ansys for static analysis, meshing, and optimization. Key optimization strategies include volume optimization, mass optimization, and remodeling. The findings demonstrate significant achievements in mass reduction, with post-optimization models showcasing a remarkable 34.35% decrease. This reduction in mass not only contributes to the overall efficiency of the gripper but also aligns with sustainability goals by minimizing material usage. Moreover, the study highlights the importance of volume optimization in enhancing structural efficiency and performance. These advancements underscore the effectiveness of topology optimization methodologies in achieving lightweight yet robust designs, particularly in the context of flexible robot grippers. The findings contribute to the broader discourse on sustainable engineering practices and pave the way for further advancements in the field of robotics. Additionally, the study emphasizes the need for continued exploration into alternative material options and further refinement of optimization techniques to meet evolving design challenges in robotics and beyond.

Keywords: *Flexible robot gripper, Topology optimisation, Volume optimisation, Mass optimisation, Remodeling.*

Submission Date: 26 July 2024
Acceptance Date: 31 August 2024

**Corresponding author:* qesk.hbee@gmail.com

1. Introduction

Flexible robotic grippers are gripper mechanisms that incorporate adaptive structures, often adopted to grasp, move, or manipulate objects in robotic systems. These types of grippers are used in a wide range of applications from biomedical implants to prostheses, robotic arm systems to industrial applications. Flexible robotic grippers are an important technological field that offers innovative solutions in line with increasing demands, especially as a result of technological developments in various sectors [1,2]. Flexible robotic grippers are often used effectively in the manipulation of delicate, porous, and traceable materials, but also have potential applications in various technical fields such as underwater applications, biomedical systems, and energy harvesting systems. In this context, the adaptive and versatile properties of flexible grippers, especially in material manipulation and their ability to function under specific environmental conditions, constitute an important research and development focus in various disciplines of engineering and science [3,4]. These grippers are typically integrated with adaptive, intelligent, and autonomous robotic systems, covering a wide range of operational and technical capabilities thanks to their ability to effectively fuse information from various sensors. This integration has the potential to effectively perform complex and dynamic tasks in a production environment integrated with industrial computers. Such integration of grippers provides significant progress and potential, especially in improving the efficiency of robotic systems, optimising operational flexibility, and making industrial production processes smarter and more efficient [5]. The design and production of flexible robotic grippers can be realized through innovative manufacturing methods, especially 3D printing. These technologies add an innovative dimension to design processes by offering a wide design space in terms of customizability, lightness, and complexity. 3D printing enables flexible grippers to be produced with geometries that were not previously possible, creating sustainable and efficient solutions [6,7]. Moreover, various multi-objective functions that take into account the salient parameters of the control response for flexible robotic systems are also proposed. In this context, these functions, developed to optimize the performance of flexible robotic systems, have the potential to make control strategies more efficient and adaptive [8]. One of the application areas for these grippers is robotic hand applications combined with haptic sensors, which are increasingly used in humanoid and medical robots. In this context, the capacity of flexible robotic grippers to provide haptic feedback can be used precisely and effectively in user interfaces and medical applications, especially when used in robotic hand systems [9].

Topology optimization is a strategy used in structural engineering to optimize material distribution. This methodology aims to organize the material distribution of a given structural design most efficiently, taking into account structural constraints and material utilization [10]. Structural constraints include factors such as material stress and strain, and optimization of these factors is aimed at increasing structural strength. This is a strategy used to achieve higher performance and durability in structural engineering projects through effective regulation of material distribution [11]. Topology optimization refers to the process of creating an optimized structure to avoid unnecessary material use and to ensure the most efficient transfer of loads to the supports [12]. This method uses density-based techniques, such as the solid isotropic material with penalty (SIMP) method, to optimize material distribution. At the same time, topology optimization aims to reduce the weight of structural designs and increase manufacturability by improving material efficiency [13,14]. This optimization method improves structural efficiency by optimizing material distribution [15]. In addition, topology optimization increases the strength of structural designs by applying material removal and additions. In this way, it is possible to optimize material distribution in structural engineering applications and increase the durability of structural designs [16].

The research conducted by Xinke Song and colleagues employed topology optimization as a strategic approach to mitigate the weight of the designed robotic arm. Leveraging the outcomes derived from static analysis performed utilizing Ansys Workbench, the application of topology optimization aimed at achieving a weight reduction target of 30% yielded a consequential reduction of 29.65% [17].

Yilun Sun et al. wanted to improve these legs by optimizing the legs designed for quadruped robots. They especially considered the standing and walking positions. After 58 iterations, the optimal design was remodeled and printed on a 3D printer. The experiment also showed that the optimized legs reduce energy consumption and vibrations during walking [18].

Yusuf et al. achieved significant improvements in the body joints of a snake-like robot as a result of an optimization study. The optimization results showed a reduction in the maximum deformation and equivalent elastic stress values, as well as a decrease in the maximum stress value. In addition, the weight and volume of the part were reduced by up to 50%. Real-world 3D printing results using PLA material confirmed the success of the optimization, showing a 48,936% reduction in the mass of the part. These findings highlight the potential of topology optimization to significantly reduce mass and volume while maintaining structural robustness in robot design [19].

Bodog and Grebenişan's study emphasizes the potential of topological optimization to reduce costs and enhance material efficiency in industrial engineering applications. The paper explores ANSYS' role in this context, assesses the efficacy of topological optimization, and introduces a methodology for improving design accuracy through parametric validation and response surface utilization. The pre-optimization static analysis yielded a total displacement of 0.173 mm and a maximum equivalent stress of 142.85 MPa. Post-optimization, the total displacement increased to 0.198 mm, with a maximum equivalent stress of 216.22 MPa. The paper underscores the pivotal role of topological optimization in the design process and provides a concise guide for ANSYS implementation [20].

Topology optimization plays an important role in optimizing gripper designs, especially in robotic systems. In passive gripper design, a successful gripper design was created by applying discrete topology optimization on the collision-free volume [21]. In a study for a pneumatic bending actuator, a design that performs elastic bending action was developed and experimentally tested using topology optimization [22]. Likewise, a robotic gripper equipped with a 3D-printed fixed-force adaptive finger was successfully designed using topology optimization [23]. In another study for an adaptive compliant gripper, a gripper with high mechanical advantages was designed by applying topology and size-shape optimization, and its prototype was fabricated using silicone rubber [24].

2. Material and Methods

In this research, topology optimization is applied to the flexible robot gripper limb. Firstly, the drawing of the model was realized in SolidWorks, a computer-aided design software. Then, one of the body additions of the assembled model was converted into a step file and imported into the Ansys program used for analysis. Following these steps, a static analysis was performed to investigate the static and strength properties of the joint depending on the boundary conditions. Based on the static analysis results, topology optimization was performed. The optimized design was redrawn based on the obtained topology optimization results and then static analysis was applied. Finally, the analysis results between the optimized part and the original part are compared.

2.1. Pre-Modeling and Static Analysis

2.1.1. Modeling of the gripper part

The flexible gripper is modeled in the SolidWorks program consisting of many parts. The part to be analyzed is the junction point of many parts. It is also the part where the rotational moment is applied to drive the moving parts. The design of this part is shown in Figure 1.

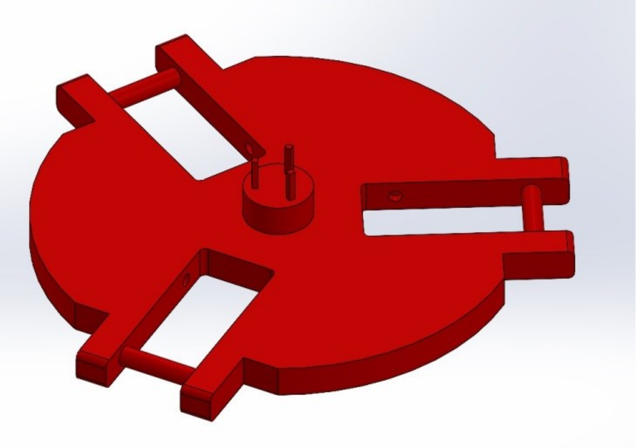

Fig.1. Modeled part

2.1.2. Identification of static loads

For static analysis, it is necessary to mesh the part since meshing is a fundamental step in the finite element analysis process. This procedure allows a complex object to be broken down into simpler parts so that the analysis can be performed more efficiently. While a denser mesh usually produces more accurate results, it increases the computation time. Simple elements allow us to more closely monitor the response of the material and make the results more localized. The mesh is also necessary to define boundary conditions and external loads. The number of nodes and elements was mathematically determined according to the mesh result of the part. In total, 238,936 nodes and 162,188 elements were created. The mass of the part was calculated in the program as 182.39 grams and the volume as 145.907 mm3. According to the meshing process, the mesh quality was found to be 82.30 percent. Mesh quality is given in Figure 2.

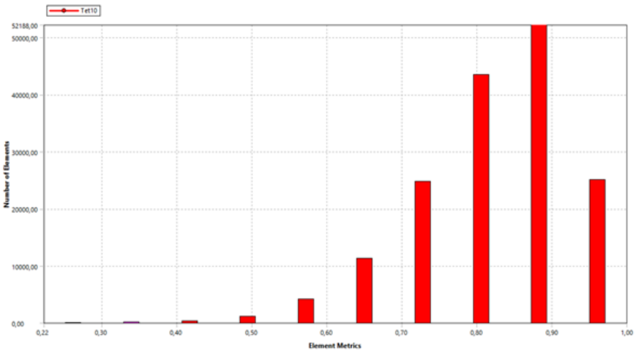

Fig.2. Element metrics

To perform the static analysis, boundary conditions must be defined for the part. This includes determining the locations where the part will be fixed and the forces to be applied. If the part contains a rotary joint, the moment, force and fixing loads must be determined. An image of the part with boundary conditions is presented in Figure 3.

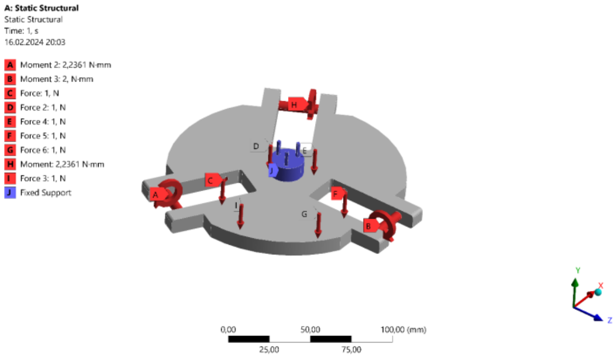

Fig.3. Boundary conditions

2.1.3. Performing static analysis

The investigation was completed based on the specified boundary conditions. The analysis evaluates the mechanical resilience of the component under the applied forces. Within engineering, the term "stress" denotes the force exerted per unit area of a material. This concept aids in comprehending the extent of strain on a material and how this strain is dispersed within it. Such understanding is pivotal in ascertaining whether materials succumb to fracturing, deformation, or other forms of failure. Figure 4 illustrates the distribution of stress.

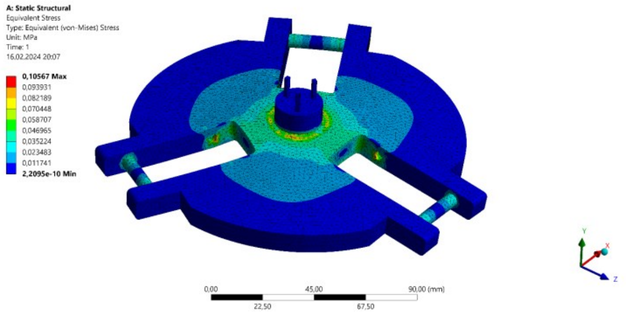

Fig.4. Result of stress

Total deformation refers to a measure indicating the extent to which a material or structural component has undergone deformation as a result of applied loads and boundary conditions. As depicted in Figure 5, the total displacement of the component amounts to 0.002936 mm. This displacement signifies the comprehensive movement of the component by the imposed boundary conditions.

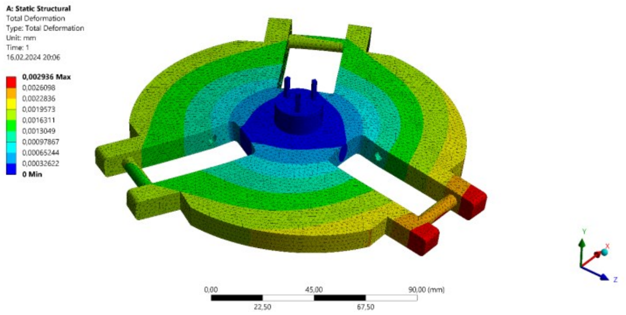

Fig.5. Result of total deformation

Elastic strain pertains to the deformation experienced by a material within its elastic threshold when subjected to an external load or stress. These deformations vanish entirely upon the removal of the applied load, causing the material to revert to its initial shape. The results of elastic strain are illustrated in Figure 6.

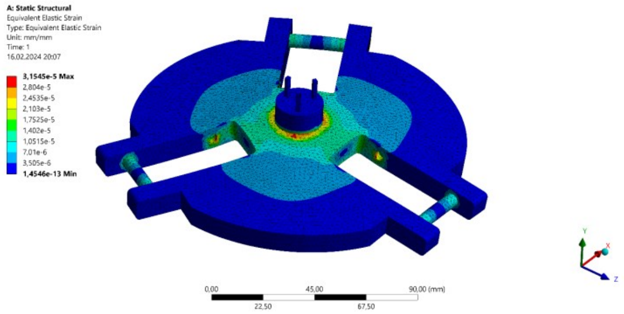

Fig.6. Result of elastic strain

2.2. Topology Optimization for Flexible Gripper

Topology optimization is a sophisticated structural improvement method used to maximize specified performance criteria by optimizing material distribution in a given design space. This process aims to achieve lightweight, yet functional and durable designs by minimizing material usage while maintaining structural rigidity and performance. The analysis was performed in Ansys with 48 iterations, during which various material distributions and geometric arrangements were evaluated. The aim is to reduce the volume-to-mass ratio by 35%, which means lightening the design and reducing the cost. Before the analysis, the volume of the part was 145.907 mm3 and the mass was 182.39 grams. The new model and boundary conditions obtained after optimization are shown in Figure 7, which includes an optimized material distribution and a more efficient structural arrangement.

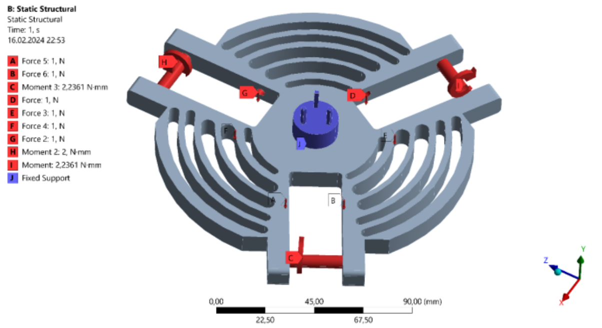

Fig.7. Modified model

The final iteration of the model underwent a thorough assessment to ensure its accuracy and reliability. This evaluation involved subjecting the model to static analysis within the Ansys simulation software, employing standardized mesh structures and specific boundary conditions. The stress distributions resulting from this comprehensive analysis are depicted in Figure 8, while the strain rates are illustrated in Figure 9, and the total deformation outcomes are presented in Figure 10. These findings play a pivotal role in assessing the overall effectiveness and potential practical applications of the model.

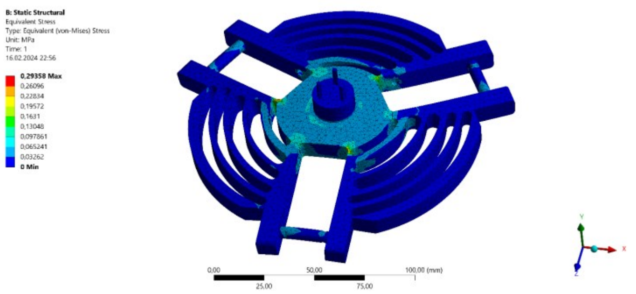

Fig.8. Stress result of modified model

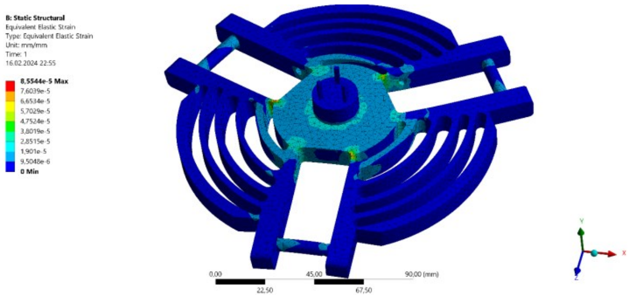

Fig.9. Strain result of modified model

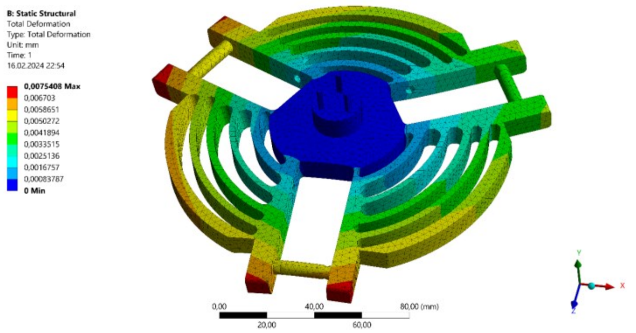

Fig.10. Total deformation result of modified model

3. Results and Discussion

Topology optimization facilitates the efficient allocation of material resources, enhancing structural integrity while simultaneously achieving notable advancements in functionality and effectiveness. Through this approach, it becomes possible to develop designs that are both lightweight and durable, optimizing material usage and fostering enhancements in mechanical characteristics.

Table 1. The Comparison of Model Results

Analysis Results	Before Optimization	After Optimization
Total Deformation (mm)	0,002936	0,0075408
Equivalent Elastic Strain (mm)	$3,1545e^{-5}$	$8,5544e^{-5}$
Von-Mises Stress (MPa)	0,10567	0,29358
Weight (g)	182,39	119,73
Volume (mm^3)	145907	95788

The comparative analysis revealed a substantial reduction of 34.35% in mass within the post-optimization model as seen in Table 1. Notably, there was a significant enhancement in stress and strain values. These advancements, coupled with the notable decrease in weight, offer opportunities for sustainable resource management and efficient utilization of raw materials. This presents a considerable advantage not only in terms of enhancing mechanical performance but also in promoting environmental sustainability.

4. Conclusion

In this study, the topology optimization of the flexible gripper part structure using PLA material is investigated. Following the analysis, critical evaluations and conclusions regarding the model and the thematic domain have been presented. A comprehensive examination of the flexible holder has been conducted. Initially, a static analysis of the selected joint part was performed. The outcomes of this initial analysis were utilized to determine the fundamental parameters of the topology optimization process. Upon the completion of optimization, the geometry and structural properties of the resulting model were scrutinized and revised to achieve a more coherent and functional design. This revised model underwent another round of static analysis under the same boundary conditions and loading scenarios used initially.

The primary aim of this study is to enhance the performance and efficiency of components and engineering models by minimizing material consumption. Structural enhancements attained through optimization techniques have the potential to prolong the lifespan of robotic elements by markedly diminishing stress and strain values. This not only augments the overall functionality of the components but also ensures prolonged and dependable operation. Such optimization strategies not only yield technical benefits but also contribute positively to environmental considerations. Particularly, optimization of energy consumption alongside weight reduction supports the broader adoption of sustainable engineering practices. The advancements realized in this study are of paramount significance. Nevertheless, the identification of any adverse effects arising during the modeling process is crucial for guiding future research endeavors. Therefore, prioritizing the minimization of deformation and refining the model further should be pivotal in subsequent stages.

In future endeavors, it is recommended to explore alternative material selections to enhance the performance, durability, and potential of the optimized model. In summary, this study underscores the potential of topology optimization in fostering efficiency gains and sustainable utilization of resources.

References

[1] Öztürk, İ. and Akaltan, K. F., Teleskop tutuculu hareketli bölümlü protezler, Selcuk Dental Journal, 8:3 (2021) 916-925. https://doi.org/10.15311/selcukdentj.799029

[2] Yetkin, S. and Koca, G. Ö., Design, control and manufacturing studies of soft robots, Uluslararası Muhendislik Arastirma ve Gelistirme Dergisi, 13:1 (2021) 74-86. https://doi.org/10.29137/umagd.706041

[3] Akdemir, B. Ş. and Kusoglu, İ. M., Review: electroactive polymers, Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 11:2 (2023) 607-624. https://doi.org/10.29130/dubited.1071302

[4] Baler, U. T., Aykin, E., Okyar, A. F. and Topaloğlu, N., Stiffness characterization of a 3d-printed thermoplastic polyurethane compliant revolute joint, Politeknik Dergisi, 25:1 (2022) 291-298. https://doi.org/10.2339/politeknik.682638

[5] Çirkin, E. and Özdağoğlu, A., Endüstri 4.0 bünyesindeki otonom robotların sürdürülebilirlik perspektifleri açısından değerlendirilmesi, Erciyes Akademi, 35:4 (2021) 1534-1553. https://doi.org/10.48070/erciyesakademi.997049

[6] Ozbaran, C. and Dilibal, S., Parallel jaw robotic gripper design and production with additive manufacturing method by using horizontal and vertical rack and pinion gear mechanism, International Journal of 3D Printing Technologies and Digital Industry, 4:2 (2020) 139-151. https://doi.org/10.46519/ij3dptdi.773133

[7] Seçkin, M., Seçkin, A. Ç. and Turan, N. Y., Investigation of discharge characteristics of hinges produced with 3d printing for prosthetic fingers, Politeknik Dergisi, 24:2 (2021) 575-583. https://doi.org/10.2339/politeknik.698316

[8] Özkaya, S., Conker, Ç. and Bilgiç, H. H., Esnek robot kol si̇stemi̇ i̇çi̇n lqr denetleyi̇ci parametrelerinin metasezgi̇sel algoritmalar kullanilarak belirlenmesi, Konya Journal of Engineering Sciences, 9:3 (2021) 735-752. https://doi.org/10.36306/konjes.896087

[9] Sümer, B., A comprehensive study on the sensing characteristics of a piezoresistive tactile sensor, Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım Ve Teknoloji, 7:2 (2019) 344-358. https://doi.org/10.29109/gujsc.515496

[10] Balta, S. and Özbaşaran, H., Computer-automated design of truss systems under manufacturing constraints, Journal of Polytechnic, (2023). https://doi.org/10.2339/politeknik.1243525

[11] Doğan, O. and Kamer, M. S., Eklemeli imalat yöntemi ile optimum düz dişli çark tasarımı ve üretimi, Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 10:3 (2021) 1093-1103. https://doi.org/10.17798/bitlisfen.912566

[12] Şanlier, C., Börklü, H. R. and Eldem, C., Laptop stand design: designs for traditional and new manufacturing methods and comparison, International Journal of 3D Printing Technologies and Digital Industry, 5:1 (2021) 65-75. https://doi.org/10.46519/ij3dptdi.836004

[13] Kip, M. and Goren, A., Topology optimization study for rear swing arm of a lightweight solar-powered vehicle, Journal of Scientific Technology and Engineering Research, (2022). https://doi.org/10.53525/jster.1141878

[14] Yaman, U., Topoloji optimizasyonu yapılmış parçaların 3b yazıcılar ile doğrudan üretilmesi, Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım Ve Teknoloji, 7:1 (2019) 236-244. https://doi.org/10.29109/gujsc.491244

[15] Canlidinç, M., Topoloji optimizasyonu ile metal eklemeli imalat yönteminin endüstriyel uygulamaları, Kırklareli Üniversitesi Mühendislik ve Fen Bilimleri Dergisi, 9:2 (2023) 552-565. https://doi.org/10.34186/klujes.1404647

[16] Saribas, I., Sürdürülebilir betonlu betonarme yüksek kirişlerin yapısal optimizasyonu, Academic Perspective Procedia, 4:2 (2021) 157-165. https://doi.org/10.33793/acperpro.04.02.45

[17] Song, X., Chen, D. and Qu, B., Topology optimization of robotic arm for gas drainage pipeline installation, In Journal of Physics: Conference Series, 2383:1 (2022, December) 012014). IOP Publishing.

[18] Sun, Y., Zong, C., Pancheri, F., Chen, T. and Lueth, T. C., Design of topology-optimized compliant legs for bio-inspired quadruped robots, Scientific Reports, 13:1 (2023) 4875.

[19] Coşkun, Y., Aydın, M. and Koçak, M. T., Topology Optimization of Snake-like Robot Limb Using Ansys, Journal of Materials and Electronic Devices, 5:1 (2023) 1-8.

[20] Bodog, A. B. and Grebenişan, G., An integrated approach of topological optimization with parametric validation and response surfaces, using ANSYS®, In IOP Conference Series: Materials Science and Engineering, 1256:1 (2022, October) 012014). IOP Publishing.

[21] Milin, K., Good, I., Lou, Y., Lipton, J. and Schulz, A., Computational design of passive grippers, ACM Transactions on Graphics, 41:4 (2022) 2-12. https://doi.org/10.1145/3528223.3530162

[22] Liu, C., Chen, L., Chi, J. and Wu, J., Topology optimization design and experiment of a soft pneumatic bending actuator for grasping applications, IEEE Robotics and Automation Letters, 7:2 (2022) 2086-2093. https://doi.org/10.1109/lra.2022.3142910

[23] Liu, C., Chung, F. and Ho, Y., Topology optimization for design of a 3d-printed constant-force compliant finger, IEEE/ASME Transactions

on Mechatronics, 26:4 (2021) 1828-1836. https://doi.org/10.1109/tmech.2021.3077947

[24] Liu, C., Chiu, C., Hsu, M. C., Chen, Y. and Chiang, Y. P., Topology and size–shape optimization of an adaptive compliant gripper with high mechanical advantage for grasping irregular objects, Robotica, 37:8 (2019) 1383-1400. https://doi.org/10.1017/s0263574719000018