Design and Analysis of a 3-Finger Adaptive Gripper

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***Abstract*—In today's modern industrial need a gripper becomes a vital element for handling components. A gripper is chosen based on the material to be handled and its properties. For any gripper to function effectively, its end application along with the work environment parameters has to be kept in mind while designing the gripper. Based on the trials conducted, the design concept is provided as part of an inventive gripper research project. The motive of this paper is to develop a 3-finger gripper and to analyze its finger with ANSYS software. A design study has been carried out for better understanding of geometrical influence on gripper functionality and performance. Directional deformation and maximum reaction moment are measured under axial and vertical loading conditions for the four metal combinations examined, and the performance is evaluated to determine the optimal material for a gripper. The findings could aid in getting desired results for specific grabbing applications, whose outcomes may lead to the creation of an application specific gripper.**

Keywords— Analysis in grasping, 3-finger robotic gripper, stress in gripper, end effector for manipulator, deformation

I. INTRODUCTION

In today's modern industrial need a gripper becomes a vital element for handling components. A gripper is so chosen based on the material to be handled and its properties. With the development in technologies, in today's world choosing a gripper for a pick and place application has become a lot easier and a wide variety of actuation technique has been developed and incorporated inside a gripper. Choosing a gripper is always a key factor for any repeated application. For any gripper to function effectively, its end application along with the work environment parameters has to be kept in mind while designing the gripper and specifications has to be drawn accordingly so as to enable the gripper to adapt with the user needs and to work effectively without the application deviation. The sensing and control feature boosts the capability of a gripper by making it more adaptive to the work material it is going to make contact with in order to avoid damaging the material as well the gripper itself.

A gripper acts as an interactive medium [1] between the robotic arm and the element to be picked. To enable this interaction to happen in a smooth manner intelligent, efficient and adaptive grippers must be designed which has to be flexible yet effective in accomplishing the picking task in an industrial environment. A soft two-finger robotic gripper [2] inspired by the human hand is being created with fabric with a maximum bending angle of 180 degrees to grasp a variety of methods and approaches for soft robotic gripping. A 3-finger 3D printed gripper [3] controlled with servo motor is designed and its grasping performance are analysed whose design can be replicated for research and educational purposes. A detailed evaluation [4] and comparison between vacuum gripper and a 3-finger gripper is made for choosing for warehousing picking and summarizes that both finds their unique application in different conditions and are based on the material to be picked. A soft adaptive origami inspired design [5] has been proposed utilizing 3-finger design for picking the objects. The 11-layer tower per finger design is cable driven and actuated by servo motors. The developed has vision-based autonomous control and evaluated with many fragile components of different size and shapes and revealed that the origami structure absorbed most of the excessive force during grasping. A mesoscopic gripper [6] is 3D printed and kinematic analysis on the gripper is made for enabling angled gripping by adapting the gripper fingertip to the shape of the object being grasped. With this novel approach, limitations of geometric constraint in picking of objects are reduced.

Contact pressure map based finite element analysis [7] is made with pressure sensing sheet to study the pressure points when picking household objects and fruits as well a stability analysis is carried out. A detailed analysis on precision grip force [8] has been carried out and compared with calculated theoretical value and experimentally measured values which results in validating the analysis. Optimal design for adaptive compliant gripper (ACG) [9] is presented for quick handling of materials with varied volume and pattern and soft-add topology optimization algorithm is carried out along with Finite element analysis is carried out to analyse the dynamic realization of the gripper. A 4-finger 16DOF gripper [10] is designed for efficient grasping and kinematic analysis is carried out to address the three major challenges namely, grasping, manipulation and releasing in desired posture. Finite Element Analysis is carried out on a 3-fingered microgripper [11] to analyse the force displacement and yield limit on the adjustable block to offset the fingers for enabling multi object gripping. A Finite Element-based grasp synthesis technique

[12] which discusses the disparity in wrench space analysis and evaluates for grasp stability by running several FE grasp simulations with various settings and identified □ as the most stable grasp. Simulation framework [13] for dynamic grasping conditions based on Finite Element method are evaluated and validated with Hertzian contact theory to obtain the stability of the grasp.

Finite Element Analysis [14] and Finite Element Method [15], [16] are the most frequently used numerical techniques for evaluating material contact behaviour by constructing a contact situation with geometry, appropriate mechanical characteristics, and model parameters. Whenever the FE model is solved, the deformation, contact force, and region of engagement of forces on the test material are obtained. The study can be useful for selecting the optimal material on comparing the contact behaviour and validating them with experimental results.

Today's fast-moving world makes use of commercially available gripper for achieving the desired tasks. But the problem that arises is due to the limitations as in some cases the gripper will not be meant for the task that it is been used for. The motive of this paper is to develop a 3-finger gripper and to analyse its finger with the ANSYS software for four different metal alloys with axial and vertical loading conditions to acquire the directional deformation and maximum reaction moment along with stress distribution for selecting the optimum material for the gripper.

II. Materials and Methods

A. Selecting a Template (Heading 2)

A three-finger metal gripper along with the mounting extension arm for precision grasping applications as shown in Fig. 1 was modelled using SOLIDWORKS, and its fingers were analysed using the ANSYS software for four different metal alloys as finger material under axial and vertical loading circumstances to obtain the directional deformation and maximum reaction moment, as well as stress distribution using the Finite Element Analysis method [14]–[16]. Instead of analysing the gripper post fabrication with pressure plates [7], it is analysed in the design level with ANSYS workbench. Wrench space formulations are frequently employed for acquiring the grip stability in dynamic circumstances, but the physical traits of the material being grasped are neglected since the formulations are predicated on static equilibrium calculations and the findings cannot be verified experimentally, hence a Finite Element based approach using ANSYS workbench is used in this paper.

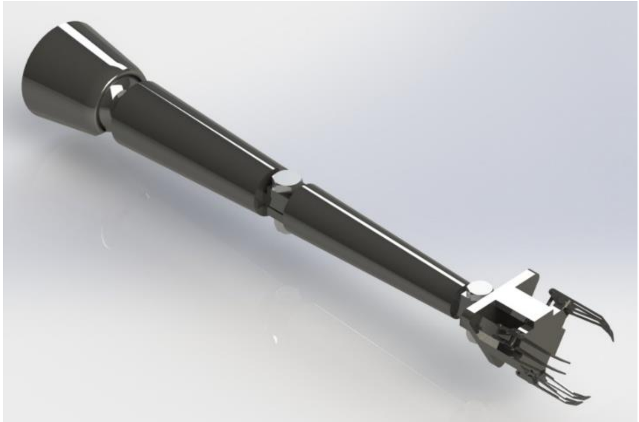

Fig. 1. Designed 3-finger gripper with arm

The overall structure is designed in a way to keep it extremely lightweight and in the unactuated state it is retracted and fully folded. The stiffness of the fingers is so determined based on the material to be grasped and the force to be applied to lift the component with coefficient of friction. The gripper is designed and the dimensional details are elaborated in Fig. 2 which depicts the complete dimensions with arm.

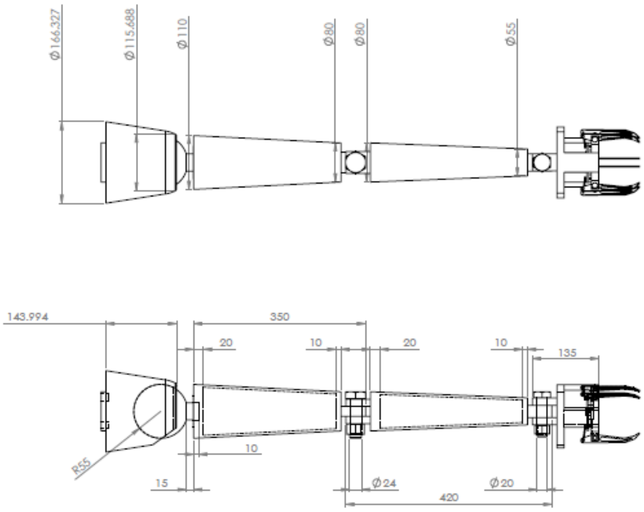

Fig. 2. Dimensional details of the gripper with arm

Four peculiar materials namely stainless steel, magnesium alloy, titanium alloy and aluminium alloy are chosen for analysis and the conditions considered for the robotic arm is given in the Fig. 3. A load of 10Kg (100N) is enforced to the palm of the robotic arm. The analysis with respect to the influence of geometry on the bending angle and grasping strength are showcased in the experimental results section.

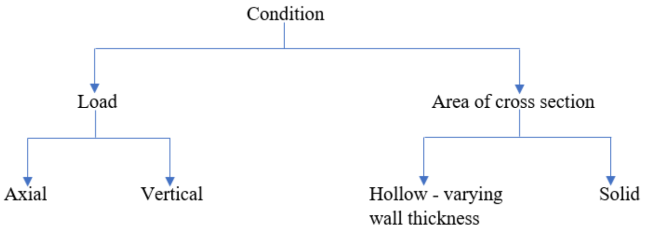

Fig. 3. Conditions for analysing the gripper

III. Results and Discussion

The designed model is analysed with the ANSYS software to obtain the stress results in different parts of the gripper and arm body. Stainless steel is chosen as the material for the entire analysis and the directional deformation on different parts of the arm are shown in Fig. 4. Fig. 5 shows the directional deformation at the finger joint plate.

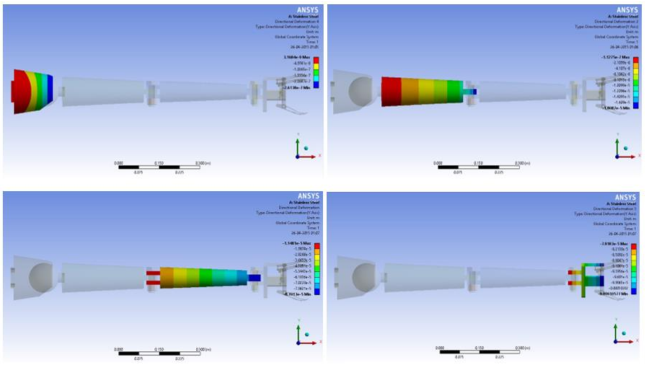

Fig. 4. Stress acting on the arm part 1 to 4

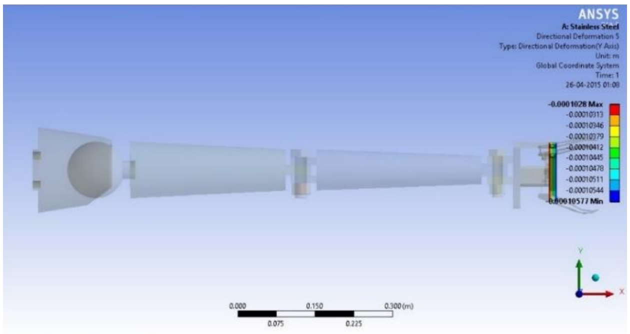

Fig. 5. Stress concentration at gripper finger joint

The equivalent Von-Mises stress are obtained for the arm joints and are elaborated in the Fig. 6 and Fig. 7 picturizes the total deformation that has occurred in the arm and its joints respectively.

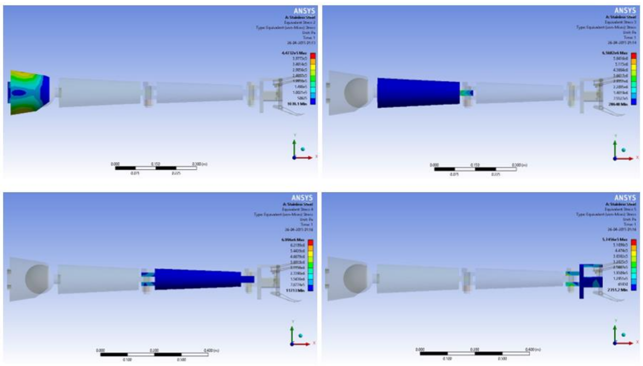

Fig. 6. Von-Mises Stress acting on the different parts of the arm

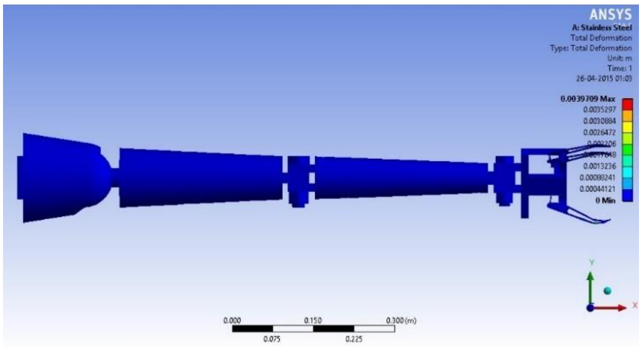

Fig. 7. Total deformation of the gripper with arm

Four different metals were taken for finger fabrication namely Stainless steel, Aluminium alloy, Magnesium alloy and Titanium alloy and the stress Vs change in area of cross section for the maximum equivalent stress for different material combinations are elucidated in the Fig. 8 under axial loading and Fig. 9 under vertical loading.

The maximum reaction moment for the links 1 to 4 is obtained for the four metal combinations during axial and vertical loading with a load of 100N and are plotted in the Fig. 10 and Fig. 11.

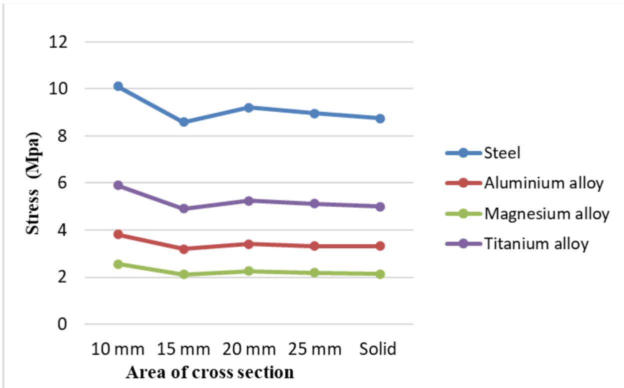

Fig. 8. Maximum equivalent stress under axial loading for different finger combinations

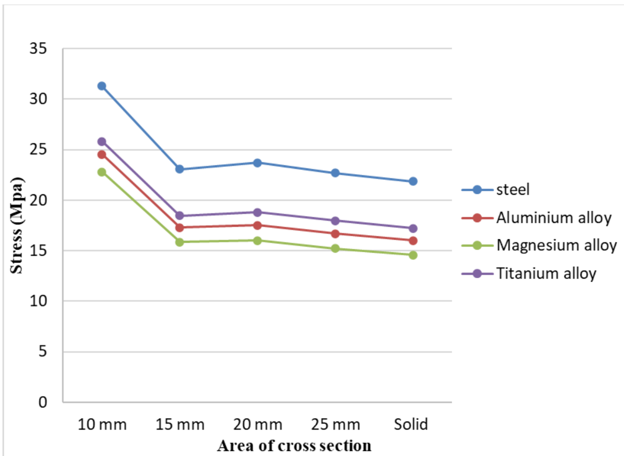

Fig. 9. Maximum equivalent stress under vertical loading for different finger combinations

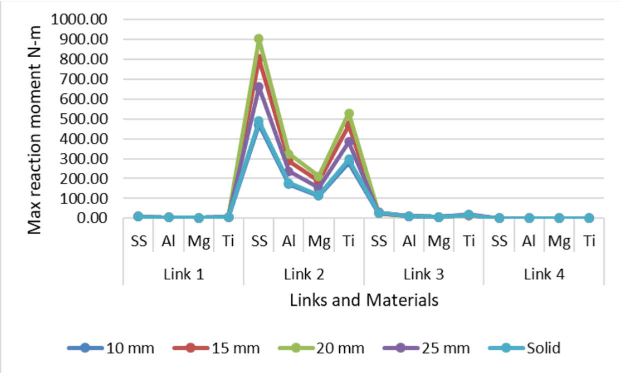

Fig. 10. Maximum reaction moment at links 1 to 4 with axial loading of 100N

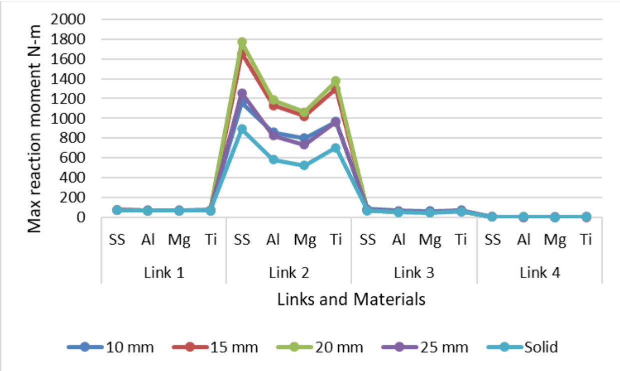

Fig. 11. Maximum reaction moment at links 1 to 4 with vertical loading of 100N

The directional deformation for the axial and vertical loading are as depicted in the Fig. 12 and Fig. 13 at an applied force of 100N.

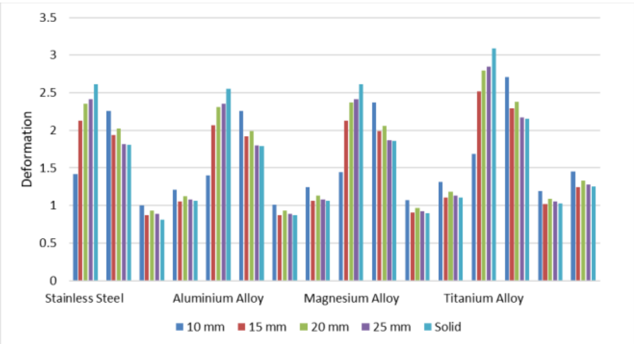

Fig. 12. Axial Directional deformation at applied force of 100N

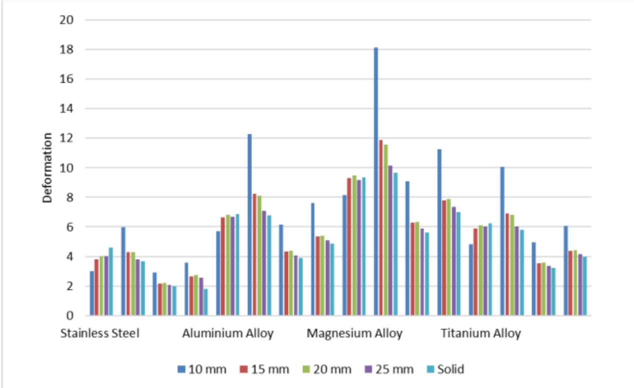

Fig. 13. Vertical Directional deformation at applied force of 100N

Tables 1 and 2 illustrate the stress, deformation, and reaction moment under axial and vertical loading situations and conditions with a 100N applied load on the four metal combinations chosen for the designed gripper model. The robotic arm is modelled in Solidworks and analysed with ANSYS workbench software under axial and vertical loading conditions with a 100N load for all the four different metal combinations. There is a decrease in stress and deformation as the cross-sectional area of the link increases and Magnesium alloy displays reduced variance in the stress value from 2.560 to 2.14Mpa. Under vertical loading conditions, all four metal combinations indicate a comparable range of stress levels. When comparing the links for directional deformation, link 1 experiences the most deformation in axial loading, whereas link 4 experiences the most deformation in vertical loading. When the maximal reaction moment from the trend is considered, the link 2 exhibits greater deviations under axial and vertical loading circumstances. The results clearly reveal that the Magnesium alloy outperforms the other three metal combinations in terms of directional deformation and maximal deformation under axial and vertical loading circumstances, proving it to be more suited for the robotic gripper finger in industrial environment.

TABLE I. RESULTS ON VARIOUS METAL COMBINATIONS UNDER AXIAL LOADING CONDITIONS

Material	**Description**	**Mass (Kg)**	**Axial Load (100 N)**									
			Maximum Equivalent Stress (Mpa)	**Maximum Deformation (m)**	**Directional Deformation (-Y Axis)**				**Maximum Reaction Moment**			
					Link 1	**Link 2**	**Link 3**	**Link 4**	**Link 1**	**Link 2**	**Link 3**	**Link 4**
					(m)				**(N-m)**			
					e-7	**e-5**	**e-4**	**e-4**				
Stainless steel	10 mm	32.165	10.102	0.004558	1.42	2.26	1.00	1.21	8.55	470.03	26.14	1.04
	15 mm	40.395	8.5871	0.00394	2.13	1.94	0.87	1.05	9.16	803.25	26.04	0.87
	20 mm	43.485	9.2037	0.004229	2.35	2.02	0.93	1.12	9.22	902.80	27.99	1.01
	25 mm	45.892	8.9536	0.004067	2.41	1.82	0.89	1.08	9.38	661.31	30.25	0.98

	Solid	49.872	8.7533	0.003971	2.61	1.81	0.81	1.06	9.47	489.58	27.47	1.01
Aluminium alloy	10 mm	11.496	3.8073	0.001708	1.40	2.26	1.01	1.24	3.4951	172.1	9.8394	0.48204
	15 mm	14.438	3.1924	0.001605	2.07	1.92	0.87	1.06	3.731	289.1	9.7869	0.42749
	20 mm	15.542	3.4004	0.001564	2.31	1.99	0.93	1.13	3.7555	325.39	10.449	0.49066
	25 mm	16.403	3.3103	0.001506	2.35	1.80	0.89	1.08	3.8148	237.02	11.294	0.4781
	Solid	17.809	3.3218	0.001572	2.55	1.79	0.87	1.06	3.8494	178.13	10.298	0.48806
Magnesium alloy	10 mm	7.407	2.5633	0.03448	1.44	2.37	1.07	1.31	2.5113	113.95	6.7036	0.39307
	15 mm	9.382	2.1238	0.032682	2.13	1.99	0.91	1.11	2.6742	188.2	6.6208	0.34133
	20 mm	10.101	2.2531	0.033123	2.37	2.06	0.97	1.18	2.691	212.3	7.0118	0.38866
	25 mm	10.659	2.1955	0.03271	2.41	1.87	0.92	1.13	2.7305	153.8	7.6101	0.37924
	Solid	11.573	2.1406	0.032623	2.61	1.86	0.90	1.11	2.755	117.6	6.9464	0.38702
Titanium alloy	10 mm	19.174	5.894	0.004175	1.69	2.71	1.19	1.45	5.3716	281.07	16.006	0.68091
	15 mm	24.08	4.9138	0.003796	2.52	2.29	1.02	1.24	5.7501	467.77	15.82	0.58755
	20 mm	25.923	5.2484	0.003932	2.79	2.38	1.09	1.33	5.7932	529.74	16.934	0.67775
	25 mm	27.357	5.1181	0.003839	2.85	2.17	1.05	1.28	5.8883	384.17	18.542	0.65817
	Solid	29.703	4.9927	0.003781	3.09	2.15	1.03	1.25	5.9427	296.37	16.703	0.67348

TABLE II. RESULTS ON VARIOUS METAL COMBINATIONS UNDER VERTICAL LOADING CONDITIONS

Material	Description	Mass (Kg)	Vertical Load (100 N)									
			Maximum Equivalent Stress (Mpa)	Maximum Deformation (m)	Directional Deformation (-Y Axis)				Maximum Reaction Moment			
					Link 1	Link 2	Link 3	Link 4	Link 1	Link 2	Link 3	Link 4
					(m)				(N-m)			
					e-7	e-5	e-4	e-4				
Stainless steel	10 mm	32.165	31.287	0.013258	3.01	5.98	2.91	3.57	78.437	1160.3	83.507	4.5093
	15 mm	40.395	23.051	0.009807	3.82	4.29	2.16	2.66	75.61	1657.8	71.688	3.8922
	20 mm	43.485	23.695	0.010127	4.03	4.28	2.21	2.72	74.461	1769.3	74.097	4.3155
	25 mm	45.892	22.673	0.009569	4.01	3.79	2.08	2.57	74.105	1257.1	77.968	4.1783
	Solid	49.872	21.839	0.009177	4.60	3.66	2.00	1.80	74.109	893.36	69.759	4.286
Aluminium alloy	10 mm	11.496	24.522	0.010117	5.69	12.33	6.15	7.60	73.39	860.89	67.405	3.952
	15 mm	14.438	17.306	0.007147	6.65	8.26	4.33	5.36	70.19	1131.1	55.483	3.4506
	20 mm	15.542	17.531	0.007251	6.83	8.09	4.38	5.42	69.002	1185.6	56.553	3.7788
	25 mm	16.403	16.696	0.006804	6.68	7.10	4.08	5.08	68.544	826.14	59.297	3.6559
	Solid	17.809	15.989	0.006498	6.85	6.79	3.90	4.85	68.499	583.36	52.695	3.7543
Magnesium alloy	10 mm	7.407	22.789	0.12885	8.16	18.15	9.10	11.25	72.408	800.57	64.397	3.8283
	15 mm	9.382	15.861	0.097551	9.30	11.89	6.29	7.81	69.138	1023.8	52.259	3.3503
	20 mm	10.101	16.004	0.096597	9.47	11.58	6.34	7.87	67.946	1064.7	53.086	3.6523
	25 mm	10.659	15.234	0.091988	9.19	10.15	5.91	7.37	67.466	735.42	55.875	3.5291
	Solid	11.573	14.555	0.089373	9.34	9.68	5.62	7.02	67.413	524.48	49.403	3.6289
Titanium alloy	10 mm	19.174	25.821	0.01309	4.82	10.07	4.94	6.08	75.268	966.27	73.776	4.1234
	15	24.08	18.454	0.00973	5.87	6.91	3.53	4.36	72.216	1297.6	61.466	3.5819

	mm											
	20 mm	25.923	18.802	0.00993	6.11	6.82	3.59	4.44	71.053	1377.8	62.964	3.9249
	25 mm	27.357	17.976	0.00945	6.01	6.03	3.37	4.18	70.627	961.67	66.933	3.7891
	Solid	29.703	17.228	0.00909	6.23	5.81	3.22	4.00	70.604	704.17	59.17	3.8989

IV. Conclusion

A design study has been carried out for better understanding of geometrical influence on gripper functionality and performance. Four different metal alloy combinations were taken for research and the evidence is picturized and briefly discussed. The results clearly show that the Magnesium alloy surpasses the other three metal combinations in terms of directional deformation and maximal deformation under axial and vertical loading conditions, demonstrating its suitability for the robotic gripper finger. The findings could aid in getting desired results for specific grabbing applications.

In the future, more research exploration will be exacted to identify additional administration indicators, namely introducing a force torque sensor to quantify the strain in the material being gripped. The outcomes of the experiments' findings may lead to the creation of an application specific gripper that can be used for a variety of grasping and manipulation tasks. Operational and economic aspects have to be placed with equal priority when designing a gripper for an application specific task.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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