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FINITE ELEMENT ANALYSES OF 3D PRINTED COMPOSITE ROBOT COMPONENT

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Abstract: *Among the most advanced technologies developed in recent years, additive manufacturing (AM) is one that meets the requirements of the Fourth Industrial Revolution. This study presents a redesigning approach of a robot gripper claw based on composite 3D printing method. The work is focused on the structure and layout of the continuous reinforcement fibers able to make a weight reduction and to increase the stiffness. The pattern strategy of fibers could be mixed to improve the mechanical response of the redesigned component at reasonable manufacturing costs. Finite element analyses (FEA) were developed to evaluate the proposed designs which used advanced materials as sandwich composites 3D printed. Compared to the conventional design of a nylon part, the reinforced models show an increment of stiffness. The redesigned models had a von Mises tension up to 60 MPa and a safety factor around 3.5. Based on these preliminary findings, future study could be developed to optimize and to customize the design of robot gripper claws using composite 3D printing technology.*

Key words: *fiberglass reinforced nylon, sandwich composite, robot gripper claw, redesign, von Mises tension, total deformation.*

1. INTRODUCTION

Starting with the commercialization of stereolithography in the mid-1980s and the development of new additive manufacturing (AM) processes in the 1990s, AM quickly became an interdisciplinary research field in academia and slowly gained foothold in industry [1-3]. AM method, also known as 3D Printing, is a technology capable of processing a wide range of complex structures and geometries starting from a virtual model under “layer-by-layer” principle.

In 2019, the global AM market grew to over $10.4 billion, crossing the pivotal double-digit billion threshold for the first time in its nearly 40-year history [4]. Compared to conventional technologies based on subtractive manufacturing, the AM processes possess some benefits [5-11]. Firstly, the material required is less than for the CNC cutting methods because the amount of material can be controlled much better in 3D printing process [12, 13]. Secondly, these technologies can reduce the production times. Due to these advantages, the AM domain grows rapidly and the available 3D printers on the market can use a variety of materials such as plastics, ceramics, metals, resins, and even composites [14-19].

Generally, the addition of fiber reinforcement enhanced the mechanical response of polymers and is a promising advancement in 3D printing [12, 20]. The advantages of composites referred to their lightweight and high strength [21-26]. Besides their applications in various fields such as aerospace, automotive or energy, the medical industry intended to use composite for developing custom craniofacial implants [27]. However, the conventional manufacturing of composites is very costly especially for prototypes and low-series production. For this reason, composites are not seeing a bigger uptake in the market. Composite 3D printing technology can make the production more effective, showing a great option to limit the costs.

The applications developed by composite AM are functional rapid prototypes, tool production, and customized parts. From automotive to aerospace, various research institutes and companies are discovering the versatility of composite AM. A short enumeration of the universities involved in this field and their practical products developed are: University of Maine (USA - largest printed boat and shelter systems for soldiers), Poznan University (Poland - carbon fiber printing robot), Masdar Institute (United Arab Emirates - ultra-lightweight architectural foam structures), and Technical University of Cluj-Napoca (Romania – new fiber-reinforced composite for craniofacial implants). Some of the companies which are developing and using composite 3D printing components are the following: McLaren-Honda (parts for Formula 1 racing team), Thermwood Corporation (helicopter parts), Eviation Aircraft (all-electric commuter aircraft developed), MultiMechanics (pipeline), Shanghai Construction Machinery (15 m long bridge), and General Motors (tools for vehicle production). Figure 1 illustrates a few printed applications made of composites.

In composite 3D printing, the fused deposition modeling (FDM) technology is one of the most used methods to fabricate parts. The main manufacturers of composite printers are Anisoprint, Continuous Composite, Ultimaker, CEAD, and Markforged. From a materials point of view, current machines can produce fiber-reinforced parts using fiberglass, carbon fiber, aramid fiber (Kevlar), or textile fibers. Moreover, the reinforcement materials can be short fibers or continuous, and reinforcement powders. A published report about the 3D printing industry, forecast total revenues for composites AM will reach $580 million by 2026 [4]. Because composite 3D printing is an emergent technology and the forming principle differs from the typical FDM process, practical case studies are still required. According to a recent survey focused on stakeholders in manufacturing, 71% of companies say that a lack of knowledge is the greatest factor on project-by-project choices to use 3D printing [28]. This report also motivates the actual work.

Since we are moving into Industry 4.0 and enterprises will aim to develop as smart factories, innovative robots will have to be integrated in their workflow [29]. For this reason, this research was focused on improving a robot component.

The aim of this case study is to present a practical example of how an existing component should be redesigned to take full advantage of the strength-to-weight benefits given by composite 3D printing. The present work provides knowledge regarding the main steps undertaken to redesign a robot gripper claw.

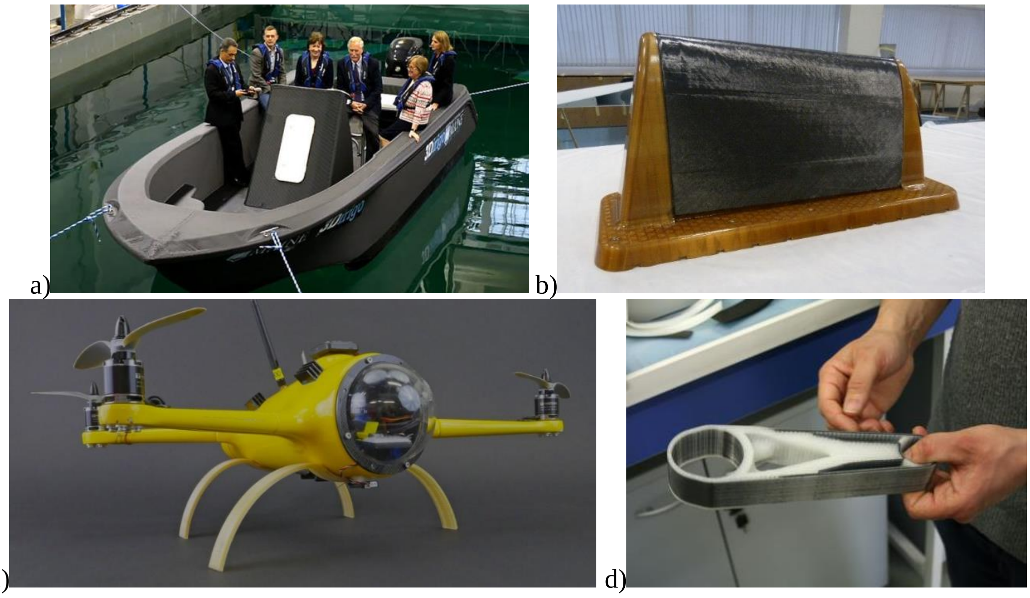

Fig. 1. Printed applications made of composites: a) Largest boat (www.compositesmanufacturingmagazine.com); b) Tool for aircraft wings (www.jeccomposites.com); c) Drone landing gear (www.khnum.asia); d) Draping robot for nautical industry (www.boatindustry.com).

To theoretically predict the mechanical behavior of the redesigned parts, finite element analyses (FEA) were developed. After redesigning the component, their volume was significantly reduced, and the von Mises stress distribution and total deformation were investigated. The topic of sandwich composite printing could be of interest for many engineering scientists, materials researchers, design engineers, and project managers.

2. EXPERIMENTAL SECTION

2.1 Composite 3D Printing

In this study a Mark Two desktop composite 3D printer was considered. The system was produced by Markforged and it was launched in 2016. This type of machine was purchased by Technical University of Cluj-Napoca and contains two nozzles. Using the first nozzle, the equipment prints the polyamide (nylon) layer, where the second nozzle allows to deposit continuous reinforcing fiber. Figure 2 illustrates the dual nozzle system. The reinforcement fibers provided by the producer are carbon fiber, aramid fiber (Kevlar), and fiberglass. Moreover, the manufacturer also produces a composite filament called onyx. This reinforced filament is a carbon fiber polyamide.

The software used to establish the processing strategy was Eiger. This software is offered by Markforged and is compatible with any printer produced by them. To start a job, initially the virtual model should be saved as .STL file and after that it could be imported in Eiger, where the fiber reinforcement strategy can be configured. Practically, after the virtual model has been uploaded in the Eiger program, it offers the following options: to establish the plastic matrix (nylon or Onyx) and to configure the fiber reinforcement strategy. The types of reinforcement fibers are detailed above. Moreover, the number of fiber layers that will be printed can also be configured, as well as the processing strategy for each layer. An example is illustrated in Figure 3, where the same part was set up with 40 layers reinforced by fibers and the maxim possible.

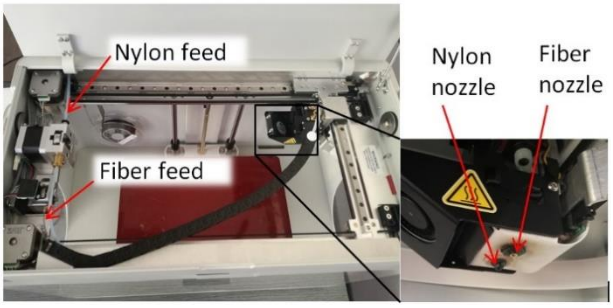

Fig. 2. Overview of Markforged printer with dual nozzle system used to print Nylon filament and fiber filament.

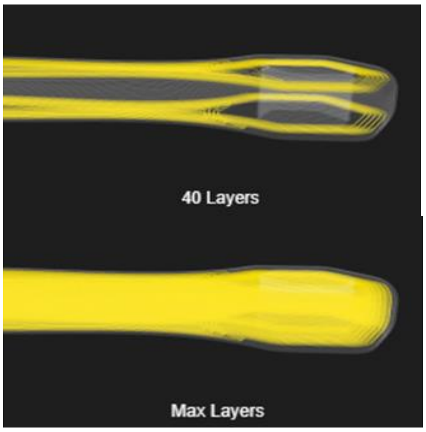

Fig. 3. Example of the fiber layers inside the printed part; Eiger software.

Moreover, the software offers the possibility to select the fiber placement pattern which can be isotropic or concentric (Figure 4). The isotropic pattern allows users to configure the fiber angle which can be 0°, 45°, 90°, and 135°. Figure 4 a-c presents an example developed on a tensile sample.

The concentric arrangement of the fibers can modify the mechanical behavior of the component. Depending on the desired characteristics, the number of concentric fiber circles can be modified (Figure 4d). Different approaches can be developed using this fiber pattern strategy. Thus, it can fabricate parts with a better resistance on the outer boundary contour but with a normal resistance inside of them. This strategy could be useful when the printed part is a component which is required especially for wear and has no special strength requirements. Also, if the part requires higher characteristics only around some inner channels, the fibers can be arranged only in those areas.

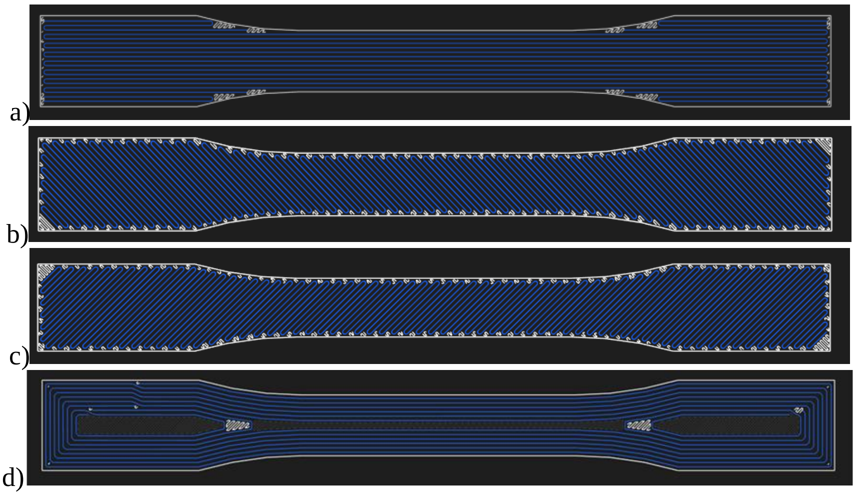

Fig. 4. Examples of fibers arrangement: Isometric at 90° (a), 45° (b), and 135° (c); Concentric pattern of fibers (d); Fiber patterns are marked with blue color and polyamide with gray; Eiger software.

Extended 3D printing studies showed that the fibers pattern can increase the tensile strength and the bending resistance [30-32]. It was found that printing with continuous carbon fibers using the Markforged printer gives significant increases in performance over unreinforced thermoplastics, with mechanical properties in the same order of magnitude of typical unidirectional epoxy matrix composites [30].

Another report demonstrates that this rapid prototyping technology for the continuous carbon fiber composite is a potential method to fabricate complex and high-performance composite parts, especially for the complex aircraft structures [31].

According to a recent study focused on mechanical results, the composite 3D printing can significantly improve the tensile strength of nylon [32]. Table 1 summarized the mechanical properties obtained on several specimens made of nylon reinforced with carbon fiber, Kevlar, and fiberglass. The isotropic orientation of the fibers increases the tensile and flexural strength of samples both for Kevlar fibers and fiberglass. Moreover, the concentric carbon fiber reinforcement demonstrates a higher tensile strength up to 216 MPa. Because the fiberglass has a reduced cost and comparable mechanical resistance with carbon fiber (see Table 1), the present study was focused on nylon reinforced with fiberglass.

To develop a possible route of fabricating the proposed designs of gripper claw, the present fiber reinforcement strategy and manufacturing simulations were developed based on the available printer (Mark Two Markforged) and software (Eiger). From a materials point of view, nylon and aluminum alloy were considered for conventional design, and composite for the redesigned models (nylon matrix reinforced with continuous fiberglass in an isotropic pattern).

Table 1. Mechanical results of Nylon specimens reinforced with carbon fiber, Kevlar, and fiberglass [32].

Specimen material	**Fiber pattern**	**Tensile test**			**Bending test**	
		Tensile Strength (MPa)	**Elastic Modulus (GPa)**	**Elongation at break (%)**	**Flexural strength (MPa)**	**Flexural modulus (GPa)**
Nylon	-	61	0.5	439.0	41.9	1.1
Carbon fiber	concentric	216	7.7	4.2	250.2	13.0
Kevlar fiber	concentric	150	3.6	4.2	106.6	4.6
	isotropic	164	4.3	4.9	125.8	6.7
Fiberglass	concentric	194	3.1	8.9	165.7	3.8
	isotropic	**206**	**3.7**	**8.4**	**196.7**	**4.2**

2.2 Redesigning the robot gripper

The objective of the redesigning activity was to reduce the weight of a gripper claw and to maintain a similar stress distribution and displacement of it. This part was chosen to test under FEA simulation the benefits of composite 3D printing. Figure 5 shows the initial design of a robot gripper claw, and the proposed designs. To redesign these parts, SolidWorks was used as CAD program. Initially, we started from a basic design of a gripper claw as shown in Figure 5b. In most cases, the gripper claws are fabricated by conventional CNC technologies (i.e., milling) or laser cutting. The main materials for this component are steel, aluminum or plastic. Because of manufacturing technology limitations, their design is simple, and the overall dimensions are 160.2 mm x 41.5 mm x 20 mm. If the part is made of aluminum alloy, its mass is approx. 178 g and the volume is 66 cm^3.

The first redesigned model presents a I profile in cross-section (Figure 5c) which is often used in constructions and metal structures for buildings and industrial halls. By making this I profile in the part structure, its volume was 48cm^3. Compared to a conventional design, the redesigned v1 model’s volume saw a reduction of 27%.

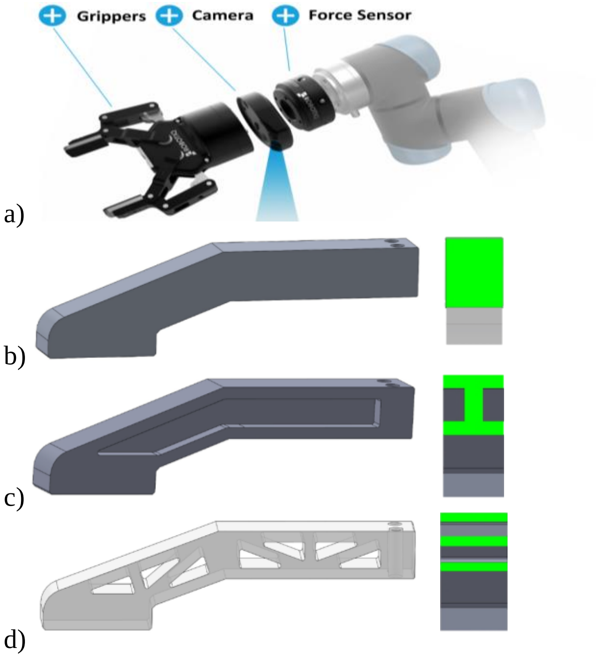

Fig. 5. a) Robot arm with 2 grippers type Robotiq UR5; Virtual model of gripper claw, isometric view & cross-section: b) Conventional design, volume 66 cm^3;
c) First proposed redesign v1, volume 48 cm^3;
d) Second proposed redesign v2, volume 53 cm^3.

	CNC milling Aluminium alloy	Laser cutting	3D Printing Nylon
Qty	Unit Price	Unit Price	Unit Price
1	€110.25	€40.58	€35.47
2	€71.43	€33.22	€26.55
5	€43.90	€16.11	€19.92
10	€30.65	€10.46	€16.35
25	€19.48	€6.53	€13.03
50	€14.32	€4.73	€11.13
100	€10.98	€3.55	€9.37

Fig. 6. Costs analysis of gripper claw (convetional design) based on manufacturing technology and quantity (Qty); Conventional design was used. Request for Quote available for quantities over 100.

The second redesigned model was chosen because it is one of the most applied geometries in building structures where the main requirements are to be lightweight and handle high loads such as industrial cranes and bridges. To reduce the part volume, we performed 7 triangular holes as it can be seen in Figure 5d. The design is like a lattice beams support, having 53 cm^3 volume. Compared to a conventional design, the volume of the redesigned v2 model is reduced by 20%.

Based on manufacturing technology and quantity required, Figure 6 illustrates the costs of a gripper claw fabricated by CNC milling, laser cutting, and 3D printing. This analysis was elaborated using the 3D Hubs platform.

The knowledge exposed in Section 2.1 assists us to develop a sandwich composite material applied for the redesigned parts. Lining elements have been produced in the past, mostly using nonmetal sandwich materials where a core is a honeycomb or a foam covered and protected by outer layers, usually made of laminated fabric composites [33]. Thanks to the Markforged printer technology, sandwich-structured composites can be simulated, prepared, and fabricated. In this work, the redesigned parts were split in two distinct areas as follows: the core material (nylon) and the skin face (nylon reinforced by fiberglass), detailed in Figure 7.

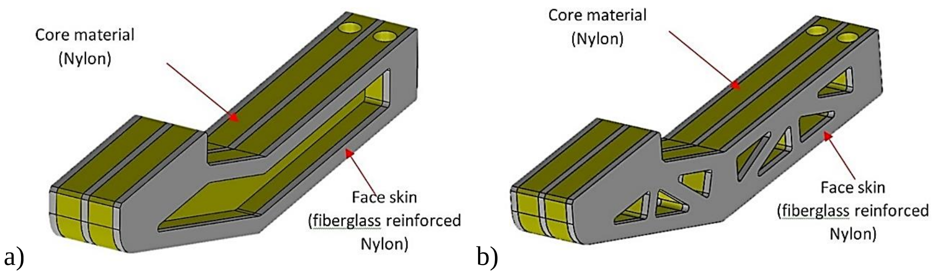

Fig. 7. Concept of sandwich-structured composite which could be 3D printed:
a) Redesign v1 model, b) Redesign v2 model.

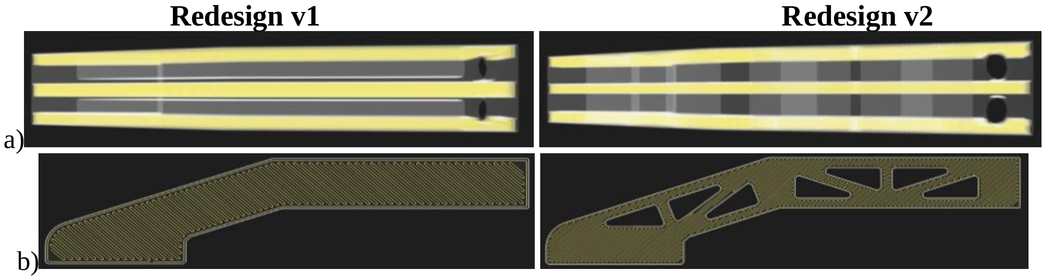

Fig. 8. Simulation of sandwich composite printing:
a) Top view, two core areas (grey) and three reinforced zones (face skin and median – yellow);
b) Cross-section with printing strategy, continuous fiberglass oriented isometrically at 45º.

The reinforced areas were chosen to coincide with the walls of the clamping bores on the gripper body to increase the strength of the component in that area. The concept of present sandwich composite has 2 core areas with 7.0mm thickness and 3 reinforced zones with 2.0mm thickness (see Figure 7). The Eiger simulations were undertaken on each redesigned model exposed in Figure 8. Also, it can be seen in the reinforcement layers. The composite printing strategy was assumed to be a nylon matrix reinforced with continuous fiberglass in an isotropic pattern (Figure 8b). Table 2 summarizes the results of Eiger simulations, being focused on manufacturing time, part weight, plastic volume, fiber volume, and production costs. From a manufacturing time point of view, the sandwich composite printing will take longer compared to typical 3D printing. On the other hand, the weight of the redesigned models is between 46 g to 50 g, being significantly lighter than the conventional design made of aluminum alloy (178 g). Adding fiberglass reinforced nylon in the gripper claw will significantly increase the production time. Due to the redesign approach, the production costs remain reasonable. These costs include material fees and labor.

Table 2. Component overview obtained using Eiger simulation.

Design	Material	Manufacturing method	Manufacturing time	Weight (g)	Plastic volume (cm^3)	Fiber volume (cm^3)	Cost** (€)
Conventional design	Aluminum alloy (AW-6060)	CNC milling	-	178.4	-	-	10-110
		Laser cutting					4-40
	Nylon	Typical 3D printing (FDM)	5h 36m	35.1	32.2	-	9-35
Redesign v1	Sandwich composite*	Composite 3D printing	9h 39m	46.6	25.7	13.9	19-55
Redesign v2			11h 20m	49.9	28.5	11.8	18-52

*Sandwich composite where the core material is nylon and the face skin areas are made of fiberglass reinforced nylon (isotropic pattern at 45° of fiberglass); For more details about how the materials are structured in these components check Figure 7; **These results were obtained using the 3D Hubs platform for instant quote, uploading the virtual models (www.3dhubs.com); The cost refers to prototype or small series production up to 100 pieces.

3. FINITE ELEMENT ANALYSES

The main physical-mechanical properties used in FEA simulations are detailed in Table 3. Assumed Poisson's ratio of composite printed fiberglass reinforced nylon was 0.33 [34]. Moreover, the flexural modulus and strength of composite were reported by Dickson et al [32]. These properties are bolded in Table 1 and were obtained on samples made of fiberglass reinforced nylon with isotropic pattern at 45º. The conventional design was assumed to be made of aluminum alloy or nylon. For the redesigned models, a sandwich composite was applied. The sandwich composite was composed of nylon and reinforced nylon, and their properties are detailed in Table 3.

The present FEA simulations were developed in ANSYS software. We presumed that the gripper should handle an 8.1 kg component made of steel. The weight of the handled component influences the clamping force. Several forces are involved in component handling but the most important is the friction force between the workpiece surface and the surface of the grippier claws. To estimate the clamping force (or gripping force) in static conditions the following aspects were considered: the coefficient of friction between nylon claws and steel workpieces, the movement type, and the maximum weight of the workpiece which must be handled [35]. The clamping force was calculated using the Equation 1:

$$F = w \text{ x } \mu \text{ x } n \text{ x } k \quad (\text{N})$$

where F is the force required to hold the workpiece, w is the weight of the workpiece, μ is the coefficient of friction, n is the number of claws, and k is a multiplication coefficient (which can take the values 1, 2 or 3).

The clamping force is influenced by the movement direction of the robotic arm. When the part is moved upwards (as opposed to gravitational attraction), the clamping force is greater than in the case of movement in the direction of gravitational acceleration (downwards). Thus, the clamping force can be estimated using Equation 1. The multiplication coefficient has the value k=3 if the part is moved in the opposite direction of gravitational acceleration (upwards), has the value k=2 if the part is manipulated in the horizontal direction and has the value k=1 if the part is moved in the direction of gravitational acceleration [35]. The following values were assumed: $w=79.4$ N, $\mu=0.4$, $n=2$ claws, and $k=3$. In this scenario, the clamping force calculated with Equation 1 was 190.6 N. Thus, a force of approx. 96 N could act on a single gripper claw. The fixing and loading conditions are shown in Figure 9, where the force was applied perpendicular on the marked surface.

Table 3. Physical-mechanical properties used in FEA simulations.

Material	Density (g/cm^3)	Poisson ratio	Flexural strength (MPa)	Flexural modulus (GPa)	Ref.
Aluminum alloy (EN AW-6060)	2.70	0.33	188[^]	25	[36] [37]
Nylon	1.12	0.35	95	0.84	[38] [39]
Composite*	1.38[#]	0.33	196	4.2	[32] [34]

[^] Flexural strength of aluminum alloy 6060 can be up to 308MPa; *Composite printed using a nylon matrix reinforced by fiberglass in an isotropic pattern; [#] Density of composite 3D printed was calculated based on Eiger simulation detailed in Section 2.

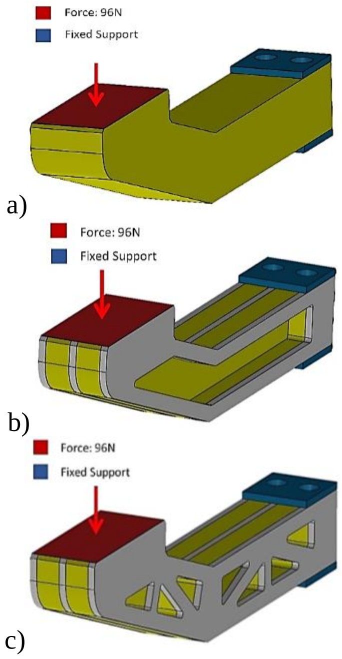

Fig. 9. Fixing and loading conditions of virtual models: a) Conventional design, b) First proposed redesign v1 made of sandwich composite, c) Second proposed redesign v2 made of sandwich composite; Rigid fixed surfaces are marked with blue; The loading area and its direction is marked with red.

3.1 Von Mises tension distribution

For each design, the von Mises tension distribution is detailed in Figure 10. Initially, the conventional design made of aluminum alloy AW-6060 was analyzed. The model was fixed between two plates (Figure 9) which simulate the fixing system within the gripper. The maximum value of the equivalent stress is 17.89 MPa and appears near the fixing area, more precisely at the edge between the fixing plates and the specimen body (see Figure 10a).

On the same conventional design, we presume that the model could be made of nylon 3D printed. As previous FEA simulations, Figure 10b shows a similar tension distribution but an increased von Mises stress up to 27.3MPa. Because aluminum alloy AW-6060 is significantly more rigid than nylon material, in Figure 10a extended tensioned areas can be seen.

The first redesign model was reinforced with continuous fiberglass, isotropic arranged. The reinforcement was made in three areas, namely on the sides of the part and in the middle area, with a thickness of the reinforced area of 2 mm.

After performing the FEA simulation, a maximum stress of 59.4 MPa was estimated (Figure 10c). Similar to the previous FEA investigations, the maximum tension appears near the fixing the area of the gripper claw. Due to sandwich composite, the highest tensions are in the fiber-reinforced areas.

The second redesign model made of sandwich composite has a von Mises distribution of tension (Figure 10d). The calculated maximum stress is about 53.9 MPa, but the flexural strength of this fiberglass reinforced area is 169 MPa (see Table 3).

In engineering, the safety factor expresses how much stronger a system is than it needs to be for an intended load. In our case, the safety factor represents the ratio between the material flexural strength noted in Table 3 and the von Mises tension determined by FEA prediction. Generally, it is recommended that the safety factor should range between 2 and 3 for different industrial parts. Under FEA simulations, we calculated a safety factor between 3.3 to 3.6 for the proposed redesigns made of sandwich composite (see Table 4).

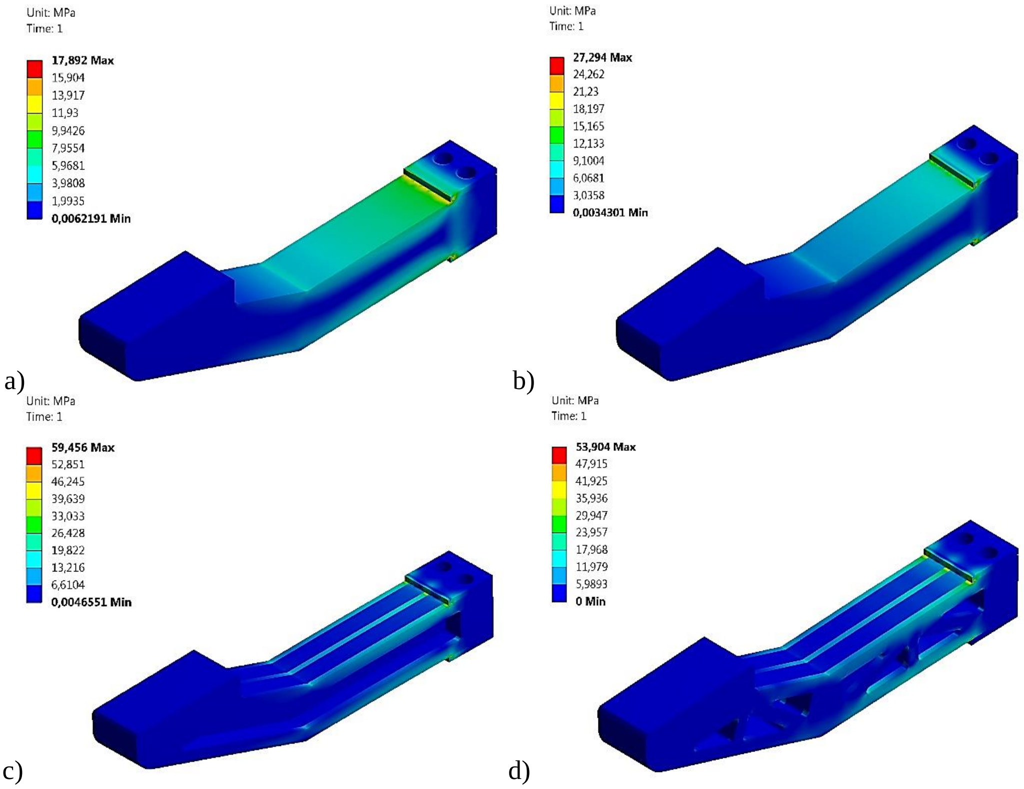

Fig. 10. Von Mises tension in gripper claw after applying 96 N force; Component material: a) Aluminum alloy (AW-6060), b) Nylon 3D printed, c) and d) Sandwich composite 3D printed.

Table 4. Summary of FEA results after it was applied a clamping force of 96 N

Design type	Material	Manufacturing technology	Maximum von Mises stress (MPa)	Safety factor	Total deformation (mm)
Conventional design	Aluminum alloy	CNC milling	17.9	Above 9	0.08
Conventional design	Nylon	Typical 3D printing (FDM)	27.3	3.5	4.3
Redesign v1	Sandwich composite	Composite 3D printing	59.4	3.3*	3.3
Redesign v2			53.9	3.6*	3.3

*Safety factor calculated on reinforced area where is located the highest von Mises tension (see Figure 10).

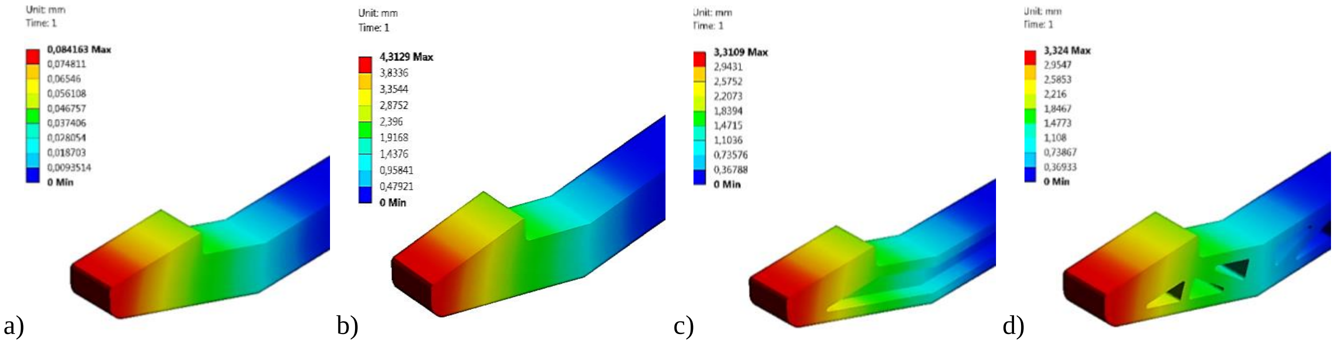

Fig. 11. Total deformation of gripper claw after applying 96 N force. Component material: a) Aluminum alloy (AW-6060), b) Nylon 3D printed, c) and d) Sandwich composite 3D printed.

If the model is made of nylon with a conventional design, the safety factor is 3.5. Thus, the volume of the proposed redesigns was reduced by 20-27% and due to the sandwich composite approach, the safety factor is similar to a conventional design made of nylon.

3.2 Total deformation

For each design, the total deformation distribution is detailed in Figure 11 and summarized in Table 4. The part made of aluminum has a displacement up to 0.08 mm (Figure 11a). A maximum displacement of 4.3 mm was obtained on the nylon part as it can be seen in Figure 11b. This value of displacement was recorded because the nylon 3D printed has a reduced modulus of elasticity. Following the FEA simulations, the redesigned models made of sandwich composite have a maximum displacement between 3.2 to 3.3 mm. The proposed redesigns of the gripper claw have a similar total deformation, archived due to several layers without reinforcement.

Improving the mechanical properties of AM formed objects is an active area of research, where the development and application of composite materials can provide unique solutions both for industrial and medical parts [40-45].

This preliminary study offers knowledge on how an existing component could be redesigned to take the advantages of composite 3D printing. This topic could be useful for many engineering scientists, materials researchers, design engineers, and project managers. From our perspective, the sandwich composites AM processed will completely change the manufacturing industry, making it much faster, flexible, and customized.

4. CONCLUSIONS

The present case study details an example of how an existing part should be redesigned to take full advantage of the strength-to-weight benefits given by composite 3D printing. Redesigned models made of sandwich composite weigh 70% less than those using the conventional design made of aluminum. Adding 3 distinct areas with fiberglass reinforced nylon in the gripper claw can increase production time compared to that of typical 3D printing using just nylon filament. Due to the redesign approach, the production costs remain reasonable. The inclusion of reinforcing fibers inside the redesigned models had a great impact on their mechanical behavior. The FEA estimations show that the maximum von Mises tension is up to 60 MPa for the redesigned models made of 3D printed sandwich composite.

Depending on redesign topology, the safety factor is between 3.3 and 3.6, being over the recommended value. The total deformation was reduced from 4.3 mm (conventional design made of nylon) to 3.2-3.3 mm (redesign models made of sandwich composite) and represents an increase of stiffness.

Future study should compare the theoretical FEA prediction with real behavior of the robot gripper claw made by composite 3D printing.

5. ACKNOWLEDGEMENTS

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Studii cu element finit privind un reper aferent unui robot, fabricat din material compozit prin tipărire 3D

Printre cele mai avansate tehnologii dezvoltate în ultimii ani, fabricarea aditivă (AM) este una care îndeplinește cerințele celei de-a patra revoluții industriale. Acest studiu prezintă o metodă de reproiectare a unei gheare aferente sistemului de prindere robotizat, având la bază fabricarea 3D cu materiale compozite. Lucrarea este axată pe structura și dispunerea fibrelor continue de armare, capabile să reducă greutatea și să mărească rigiditatea reperului. Astfel, dispunerea fibrelor ar putea fi combinată pentru a îmbunătăți răspunsul mecanic al componentei reproiectate. Tehnologia de tipărire 3D luată în considerare permite dezvoltarea chiar și a compozitelor de tip “sandwich”. Analiza cu elemente finite (FEA) a fost dezvoltată pentru a evalua noile modele propuse, fabricate din materiale avansate ca compozitul de tip sandwich tipărit 3D. Comparativ cu designul convențional al piesei din nailon, modelele armate au o rigiditate crescuta. Modelele reproiectate au distribuit o tensiune von Mises de pana la 60 MPa si au un factor de siguranta de aproximativ 3.5. Pe baza acestor constatări preliminare, studii viitoare ar putea fi dezvoltate pentru a optimiza proiectarea diferitelor gheare de prindere ale roboților, utilizând pentru fabricarea lor tehnologia de tipărire 3D cu materiale compozite.

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