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DEVELOPMENT OF RECYCLABLE JOINTLESS PLASTIC GRIPPERS FOR USE IN THE MEDICAL TECHNOLOGY SECTOR

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Abstract: Medical grippers can be used for various purposes. They are a standard instrument in medical technology and are widely used every day for multiple applications. Jointless grippers, which, due to their geometry and material properties, allow for an easy gripping function, are very welcome to the medical sector in order to make the work and especially the hygiene or sterilisation of the products easier. The application of a single-use instrument made of thermoplastic and 100% recyclable plastic is an ideal response to the current trend toward the increasingly frequent application of single-use instruments in medical technology. Moreover, the infected plastic material can be easily disposed of.

The development of a new type of gripper made of plastic is a step towards partially fulfilling this need. This article presents the development and validation of a jointless medical gripper produced by additive manufacturing and injection moulding technologies, using a compliant mechanism and thermoplastic material.

Keywords: *Gripper; Jointless; Surgical products; Medical sector; Single-use products*

1. INTRODUCTION

In hospitals and medical facilities, many instruments made of metal are still in use. The trend is moving more and more towards plastics and single-use tools for the maintenance of a sterile environment. (Blessy J., Jemy J., Nandakumar K., Sabu T. 2021) In medical

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technology, more than 50% of all materials used are already made of plastic. In the future, the need for single-use plastic surgical products will increase more and more. (Sastri V. 2021)

The use of plastics has many essential advantages in medical technology. In addition to the low weight and the lower purchase price, the easier handling and the possibility of processing recyclable materials speak using polymer materials in medical technology. (Gamba A., Napierska D., Zotinca A. 2021). The forceps should be produced as a sterile disposable instrument and thus, in contrast to the tools made of metal, do not have to be sterilised after each use, which is time and cost-intensive. (Sun Y., Zhang D., Lueth T. 2020)

A new feature of this development is that the whole gripper consists of a single component and therefore does not have to be assembled in a further step. The gripper was designed so that the gripping area clamps safely and closes as soon as a specific force is applied using an adaptadet-compliant mechanism. (Hasse A., Campanile L. F. 2009) This type of gripper has many advantages, such as lightweight, easy use and recyclability, and the fact that it can be mass-produced through the injection moulding technique.

The gripper based on the compliant mechanism's development, optimisation, and production is presented in detail in the following chapters.

2. CONCEPTION AND DESIGN

The goal was to develop the gripper so that it consists of a single component made of plastic, can be produced in one step for mass production, and is fully functional. The gripper should be 100% recyclable, weigh a maximum of 20 g, and be designed for a maximum force of 300 N. The focus here was on the optimal force transmission from the gripping area of the gripper to its top using a compliant mechanism with a structural optimization approach. The closing of the gripper is caused by the force generated when the handles are tightened and transmitted to the tip of the gripper through its structure. The centre of the gripper has a decisive role as it transmits the motion and is responsible for the optimal movement of the gripper. The geometry of the centre is also an important factor for the optimum force transmission from the gripping area to the tip of the gripper, as well as for the optimum sustainment of the clamping force.

Various structures featuring different centres (see Figure 1 – red circles) and thicknesses were designed in CAD and validated using Finite Element Analysis.

The collected results were then evaluated against the defined requirements, and the best geometry combination was created as a CAD model, see Figure 1.

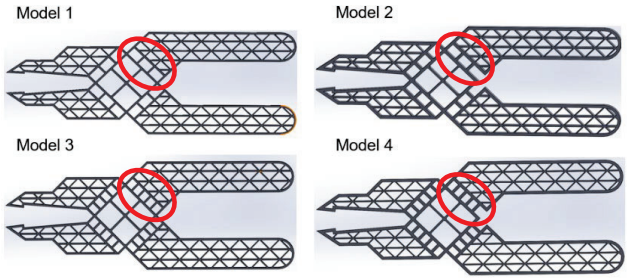

Figure 1. Different designs of the gripper as CAD model

3. DEFINITION OF THE OPTIMAL GEOMETRY

The Finite Element Analysis (FEA) is used to analyse virtual components with the help of a mathematical calculation (Barkanov, 2001). The FEA is a general numerical method used in various physical tasks. The main application of FEA analysis is for strength and deformation studies of solids with geometrically complex forms. For the FE Analysis of the gripper, tetrahedrons elements were used, and a PLA material was created and used. Here, the displacement of the tip, the strain, and stress on the part are calculated and analysed under a defined force. The simulation of how a human hand presses the gripper was simplified using a specific force of 100 N distribute on the whole gripping surface (see Figure 2).

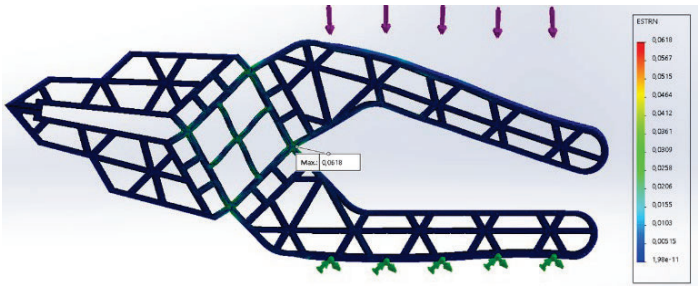

Figure 2. Finite element analyses (maximum strain [%]) on the 3D gripper model

For the static simulation, the force was applied to the upper side of the gripper (upper handle) while the other side of the gripper (bottom handle) was constrained. In total, four different structural models (M1-M4) were investigated using the Finite Element Method (FEM). Each model was further divided into four other variations by changing the walls thickness and the width of the gripper. The design parameters considered to exert a strong influence on the behaviour of the force transmission thru the structure were the wall thickness of 1 mm (W1) and 1.5 mm (W1.5). and a gripper thickness of 5 mm (T5) and 10 mm (T10). In summary, 16 models with different wall thicknesses and geometries were analysed. The FEM was used to determine the maximum displacement of the tip, the stress, and the maximum strain of the gripper. The results are shown in Table 1.

Table 1. The results of the FEA (Mx: Model number, Wx; Thickness of the wall; Tx: Gripper thickness

	Model 1				Model 2			
Version	M1_W1_T5	M1_W1_T10	M1_W1,5_T5	M1_W1,5_T10	M2_W1_T5	M2_W1_T10	M2_W1,5_T5	M2_W1,5_T10
Maximum stress [N/mm²]	110,5	198,2	83,14	107	90,9	346,3	114,8	176,3
Maximum displacement [mm]	11,68	21,3	7,82	9,93	9,52	37,8	8,29	16,89
Maximum strain [%]	0,0269	0,048	0,0219	0,027	0,0215	0,0843	0,0194	0,042

	Model 3				Model 4			
Version	M3_W1_T5	M3_W1_T10	M3_W1,5_T5	M3_W1,5_T10	M4_W1_T5	M4_W1_T10	M4_W1,5_T5	M4_W1,5_T10
Maximum stress [N/mm²]	98,35	213,1	77,1	137,7	95,6	241	90,38	148,3
Maximum displacement [mm]	10,8	18,32	6,08	8,16	10	27	7,09	12,3
Maximum strain [%]	0,024	0,04	0,0191	0,0281	0,0229	0,0591	0,0231	0,04

In Figure 3, the maximum displacement from the FEA of the gripper was evaluated. The design concept specifies 12 mm (red line in Figure 3) for the width of the top; therefore, the maximum displacement at the top of the gripper should not exceed this value. Based on these results, some versions could already be eliminated. The evaluation also reveals that the required properties of the gripper do not benefit from an increased gripper thickness.

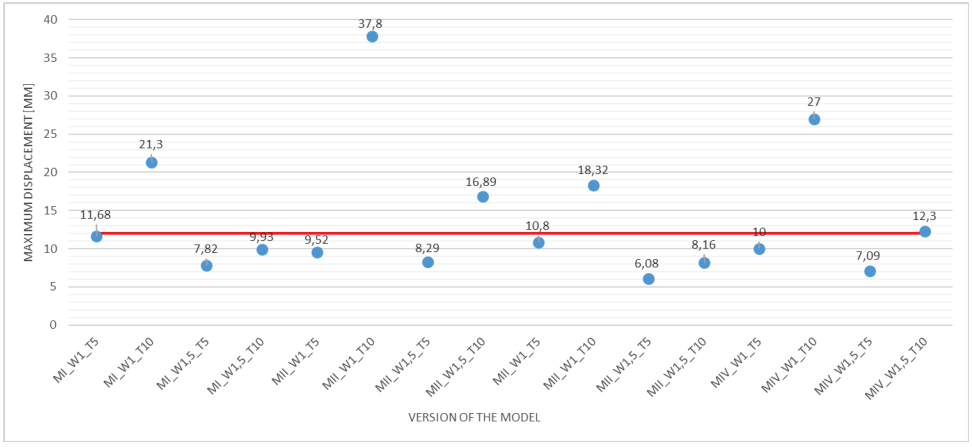

Figure 3. The maximum displacement at the top of the gripper resulting from the different designs.

Figure 4 shows that the maximum strain (grey line) is very similar for the remaining versions. This means that neither the gripper nor the wall thickness have a significant influences on the maximum strain. The green line from the figure displays the maximum stress inside the gripper. The load should not be too high to prevent critical stress concentrations in some areas, which could avoid the gripper from breaking easily while being used.

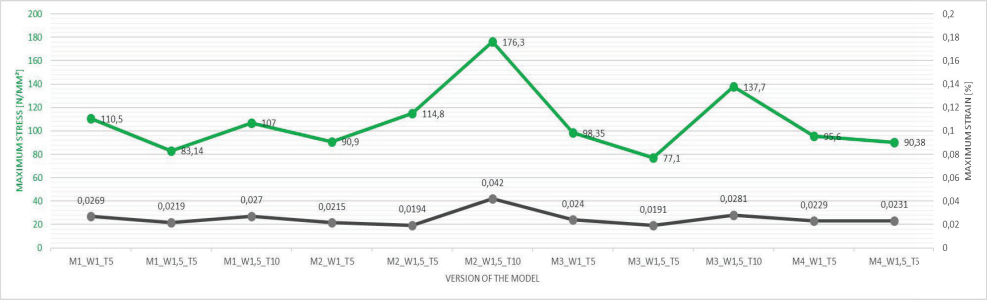

Figure 4. The maximum stress (green line) and the maximum strain (grey line) of the different gripper models from the FEA.

Based on these results, model 2, featuring a wall thickness of 1 mm and a thickness of 5 mm, was selected as the optimum gripper for the later fabrication and tests. The goal of the FEA was to determine the optimal structure of the gripper, especially the thickness of the wall and the gripper.

4. TRANSFER OF THE VIRTUAL MODELS TO RAPID PROTOTYPING

In the next step, all the knowledge that had been gained in terms of material and geometry was transferred to the rapid prototyping process. Rapid prototyping is an additive manufacturing process in which a virtually created model is transformed for the first time into an individual 3D prototype, produced with different techniques. Figure 6 shows the created virtual model of the single-use gripper for the 3D FFF (Fused Filament Fabrication) printer.

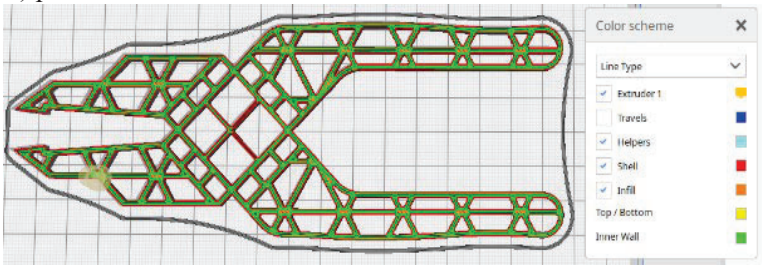

Figure 5. The virtual model of the gripper prepared for 3D FFF printer

Using this process, the virtually generated model was transformed into prototypes for the first time with the help of a 3D printer to check the function of the gripper and the essential design concept. Different parameters, such as the nozzle diameter of the 3D printer, and the layer thickness, which can influence on the strength or elasticity of the gripper during 3D printing, were analysed in detail. During this analysis, it was also found that wrongly generated printer tracks can cause holes in the component or bad adhesion between the individual layers. In the next step, the grippers were manufactured as 3D printed models (see Figure 5) using various materials (PLA, PP, Medical ABS, PA, PET CF15, and PETG) applying the FFF technology. The rapid prototyping process helps the developer transform the concept idea into a realistic model and to convert it into high-precision prototypes. The gripper was optimised several times, and some more parts were produced via FFF technology. After optimizing the geometry, the new gripper geometry was prepared for the injection moulding process. Several grippers were produced via injection moulding process by the company priomold GmbH.

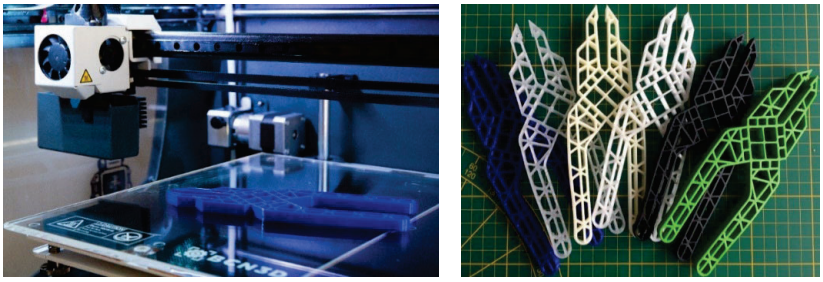

Figure 6. Manufacturing the prototypes with a 3D FFF printer using different materials

5. RESEARCH AND EVALUATION OF GRIPPER PROPERTIES

The quality features of the injection-moulded disposable grippers made of different materials were mechanical tested in detail for characterisation and comparison purposes. For the pressure test, the grippers were statically stressed for two minutes applying a constant force of 300 N using a test apparatus in the universal testing machine (see Figure 7).

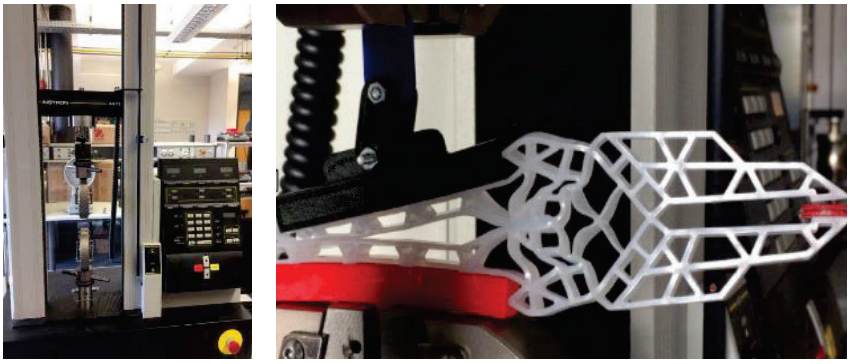

Figure 7. Testing of the mechanical properties of the inceted moldedgriper with a universal testing machine.

Here it was analysed which force exerted on the handles is necessary to make the tips of the gripper touch each other and which maximum clamping force can be measured at the tip. With this equipment, different grippers were tested to study the influences of the polymer material used in detail, their geometry, and the influences of the manufacturing process. The tests showed that a force of up to 50 N was measured at the tip of the gripper. This force ensures the safe gripping of medical products such as swabs, plasters, and many others.

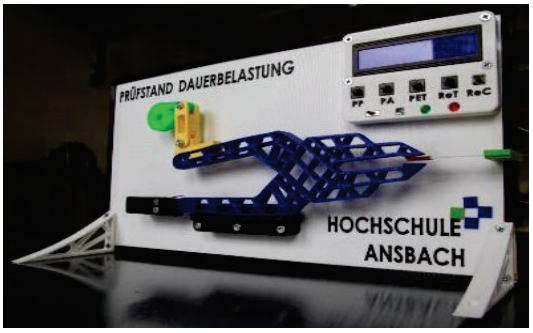

Figure 8. Test device for dynamical testing of the gripper

In addition, the dynamic mechanical load of the grippers was simulated with the help of a self-developed testing system (see Figure 8) to discover weak points in the geometry. The grippers were cyclically opened and closed about 150 times for 60 minutes.

The dynamic and static pressure tests showed that various (PP and PETG) materials did not sustain the required loads and broke during the test. In addition, the material used must be approved for medical/pharmaceutical purposes. An HD-PE polymer was discerned as an optimal material for the injection-moulding process of the grippers.

The goal of the mechanical tests was to study different types of materials with the optimal structures determined during the FEA.

6. CONCLUSIONS

Using a disposable gripper made of recyclable thermoplastic material optimally picks up the current trend toward the increasing use of disposable instruments in medical technology. A jointless gripper based on the compliant mechanism, which allows for a gripping function based only on its geometry and material properties, is in great demand from the medical sector to simplify the work and especially the hygiene. The research results show that with the developed gripper, a force of up to 300 N can be applied to the handles without causing the gripper to break, which should be sufficient for a hand-operated device. The present research proves that it is possible to manufacture a jointless gripper through FFF as a prototype and injection moulding for mass production using thermoplastic materials. Furthermore, the mechanical static and dynamical tests prove that the jointless gripper, based on the compliant mechanism produced by the injection-moulding process and using a medical-grade thermoplastic as PE, can fulfill the requirements for a medical device.

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Conflict of interests

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

B.M.A conceived, designed, performed experiments and analysed the results, wrote a part of the manuscript S.A. and Z.M. analysed the experiments, technical proof of results, wrote and reviewed the manuscript. S. T. provide the material and injection moulded parts, and reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

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