An Innovative Method to Connect 3D Printed Components Using a 3D Printed Compliant Mechanism

Patrich Ferretti, Eleonora Guidotti, Gian Maria Santi, Giulia Alessandri, Giulio Galiè
Department of Industrial Engineering
Alma Mater Studiorum University of Bologna
Viale Risorgimento, 2 – 40136, Bologna, Italy
patrich.ferretti2@unibo.it, eleonora.guidotti@studio.unibo.it, gianmaria.santi2@unibo.it,
giulia.alessandri5@unibo.it, giulio.galie2@unibo.it

Abstract

The following paper focuses on designing an innovative method for connecting 3D printed components. This is an important topic to weakness the problem of printer dimensions. The idea of connecting different parts in a larger one using compliant mechanism starts from a real application concerning the building of molds with dimensions beyond the desktop size for carbon fiber lamination. The goal is to maximize the mold quality without the need of excessively increase in printing time. These aspects provided an opportunity to delve into the topic of dividing 3d printed molds and the subsequent assembly, as well as disassembly for the extraction stages of the laminated part. The goal of the paper is to propose a mechanism capable of facilitating all stages of part production, from mold assembly to component extraction. In addition, the idea is to develop a mechanism that does not require the use of specific tools.

Keywords

3D printing, FDM, carbon fiber lamination, compliant mechanism, assembly, disassembly.

1. Introduction

This research considers 3D printing technology as a possible tool in the manufacturing process of finished part. This assumption is of fundamental importance because it moves the focus from the finished product to the production of the component itself. Reference is often made to prototypes or finished products made by 3d printing, but it is especially in the production phase that significant advantages are observed such as: the lowering of material cost, the absence of hazardous dust or toxic residues, and the possibility of application to different materials.

However, the research aims to overcome a major limitation related to the maximum size of the component that can be printed with a desktop device (about 300x300x300 mm). Practical solutions, especially non-reversible ones, vary from gluing to physical connections (example plugs). Reversibility was imposed as a condition since in the extraction phase of the laminated part from the mould, the possibility of opening the mold in two or more parts reduces time and difficulty as well as the possibility of part fracture.

In the field of 3d printing, FDM (Fused Deposition Modeling) technology best corresponds to the requirements and needs of the presented case study.

1.1 Objectives

The objective of the study is to ensure an intuitive, solid and reliable yet easily reversible connection for large, finished components made in 3d printing. The 3D printing technology chosen is FDM since it offers the possibility of building compliant mechanism printed in place using the same material as the component to which it is applied, without affecting cost and processing time.

2. Literature Review

Additive manufacturing processes, most known as 3D printing is a rapid prototyping and manufacturing technology, which allows to portray 3D structures at a reasonable high speed at a low cost (Barua et al. 2021), (Jones et al. 2021), (Wang et al. 2017), (Pyo et al. 2017), (Ge et al. 2020). These processes have proved to have exciting potential in diverse industries from automotive (Nichols et al. 2019), robotics (Kim et al. 2018), (Kuang et al. 2018), towards materials (Della Bona et al. 2021), (Tan et al. 2019), electronic devices (Sachyani et al. 2021) (Wei et al. 2018), and even bioengineering (Yadid et al. 2022), (Schiros et al. 2021), (Qiu et al. 2018), (Markstedt et al. 2015) and even food production (Zhang et al. 2021), (Mantihal et al. 2020). This production method has been widely accepted in the manufacture of parts of polymeric origin, for which a variety of additive manufacturing technologies are used, among which we can mention Fused Deposition Modelling (FDM), among the most widely used. Moreover, other important factor in the choice of this technology is the possibility of manufacturing the component in any part of the world, without the need to depend on a specific supplier and therefore to produce the product on site, avoiding the expected waste of time as well as costs of transport and supplier logistics; this flexibility makes the design shareable worldwide through augmented reality (De Amicis et al. 2018), which could be used to integrate product and process evaluation (Frizziero et al. 2021), (Donnici et al. 2019).

However, it is not possible to change the manufacturing technology of a component without adapting its design. In fact, it must be adapted and modified by following the best practices of the specific printing technology to obtain a component that allows the same performance, but can be made with the chosen technology, even if made through procedures involving the use of 3D printing (Ferretti et al., 2021). Moreover, rapid prototyping technologies have enabled the development of innovative compliant mechanism methodologies in order to improve and simplify component fits and designs (Shaha et al. 2022), (Moritoki et al. 2021).

3. Methods

3.1. Part modelling process

All components were designed using PTC Creo. The modelling of the components is strictly related to the manufacture process used, in this case FDM. Particular attention was carried out to avoid the creation of overhangs to eliminate the generation of supports making possible to apply the connection to different components and materials. In general, strategies of Design for 3D printing were applied to minimize the waste of material improving the result of the final component.

3.2. Materials

The only material used for the case study is PLA FILOALFA®. Table 1 shows the main mechanical properties as declared by the manufacturer.

Table 1. Main Mechanical Properties for Used Material

PLA FILOALFA®		
Properties	**Value**	**Method and Condition**
Density	1,24 g/cm3	D792
Tensile Strenght	53 Mpa	D790
Tensile Modulus	3,6 Gpa	D882
Tensile Elongation	6%	D882
Heat Deflection Temperature	55°C	E2092

The choice of material is linked to the maximum cost-effectiveness. PLA is indeed a cheap but rigid plastic material that suits well for the purpose of this paper. It was chosen even for the main component but in any case, the link would works regardless of the material used for the main part.

A common PLA, which has a glass transition temperature (Tg) of about 55°C (Table 1) is enough for the carbon fiber lamination application.

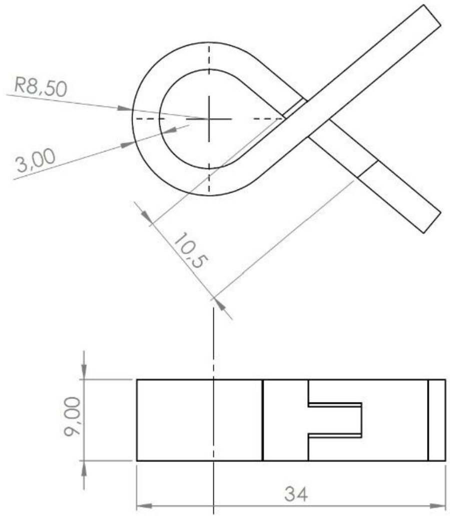

Figure 1. 2D draw of the connector used for the case study

Figure 1 shows the geometry of the connection key that has a thickness of 3 mm, an overall length of 34 mm and a height of 9 mm. The connector key and the cavity designs exploit the possibilities offered by FDM printing. In particular, they are made by one-piece and printed in place. The connection cavity has an undercut that ensures a solid interlocking and feedback during assembly and disassembly stages.

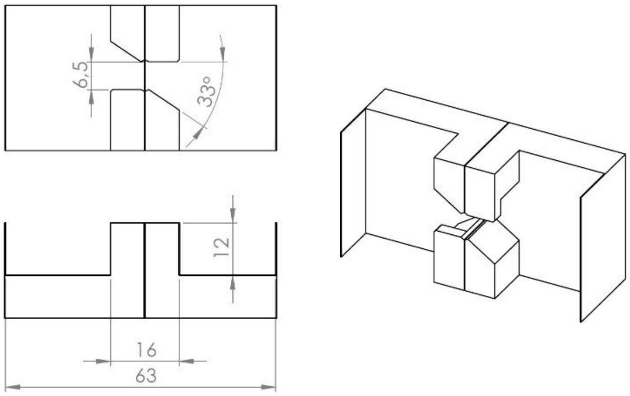

Figure 2. Drawing of connection cave.

The connection cavity design is deliberately asymmetrical and repeatable, so that it can be quickly placed at regular intervals along the side of the part. The number of connectors and the distance between them is related to the size and thickness of the part to be joined, as well as its function and the amount of stress it will be subjected to. Figure 2 shows the geometry of the connection cavity showing its modularity. If the parts to be connected have a high thickness, it is possible to scale both connector and key mechanism without altering the final result.

4. Data Collection

4.1. Printing Strategy and Settings

The main printing parameters used within the Ultimaker Cura to perform slicing before printing are shown in Table 2..

Table 2. PLA FILOALFA® Slicing Parameters for connector

Parameters	**Value**	**Unit**
Layer height	0,2	mm
Line width	0,4	mm
Wall line count	2	/
Z seam alignment	shortest	/
Top layers	3	/
Bottom Layers	3	/
Skin overlap percentage	20	%
Inifll density	20	%
Infill pattern	grid	/
Infill overlap percentage	25	%
Printing temperature	205	C°
Flow	100	%
Print speed	60	mm/s

Table 2 shows that the component has a low infill of 20% and no support. This is justified by significantly reducing costs and printing time. Figure 3 shows five connectors ready to be printed. The connectors were printed in place thanks to FDM technology. The infill overlap is set to 25% in order to guarantee strength and toughness. The infill density is set at 20% and it is enough to give the right preload force and maintain it over time. The huge advantage of FDM technology is the ability to make multiple copies of the same component without increasing the overall printing time.

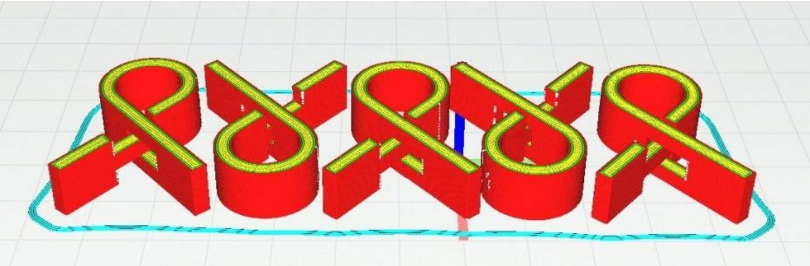

Figure 3. Connectors preview post slicing.

Table 3 summarizes the main parameters used within the Ultimaker Cura to perform slicing before printing of the cave's detail, with FILOALFA PLA.

Table 3. PLA FILOALFA® Slicing Parameters for cave

Parameters	**Value**	**Unit**
Layer height	0,2	mm
Line width	0,4	mm

Wall line count	2	/
Z seam alignment	shortest	/
Top layers	3	/
Bottom Layers	3	/
Skin overlap percentage	20	%
Inifll density	20	%
Infill pattern	grid	/
Infill overlap percentage	25	%
Support structure	normal	/
Support Overhang Angle	60	°
Support density	15	%
Printing temperature	205	C°
Flow	100	%
Print speed	60	mm/s

Figure 4 shows the post slicing of the cave isolated from the main component to highlight how its design generates very little support due to a minimum area of two layers in the contact surfaces.

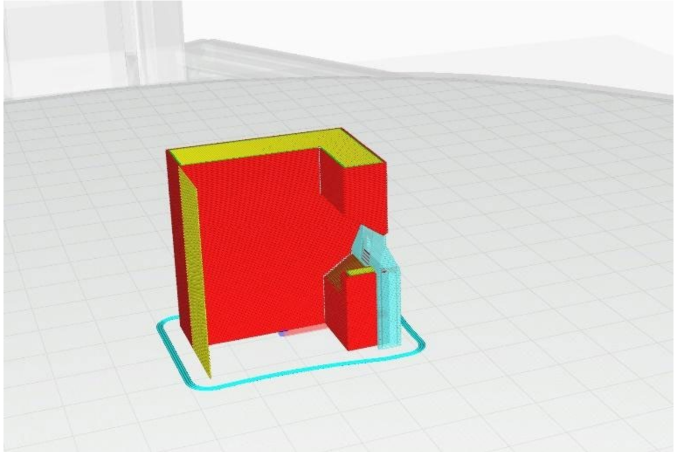

Figure 4. Cave preview post slicing.

5. Results and Discussion

Figure 5 shows PLA parts connected using the connection cave and the connection key. Figure 6 shows parallel application of multiple keys and figure 7 shows an orthogonal application.

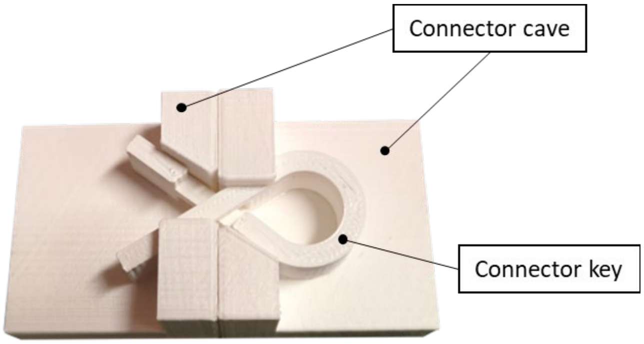

Figure 5. PLA Simple connection

Figure 6. Parallel Application of connector keys over a connection cave

One of the advantages of the presented connection is its self-centering feature. Because of the elasticity of the key and the geometry of the cave, the load is oriented in a way that ensure a stable position even under ill conditioned loads. The solidity of the connection is good even with one key, but increases exponentially if more keys are arranged in parallel or orthogonally. The experience showed that the connector after repeated preloads, insertions and disconnections maintains its behavior and preload. If it is left inserted for long time, even over a month, it does not lose strength and can be reused. It is important to emphasize the retention of mechanical properties, as the reversibility of the connection was an essential requirement of the application.

Figure 7. Orthogonal Application of connector key

6. Conclusion

This study showed how 3D printing can be revolutionary not only for creating finished components, but also if integrated into the manufacturing process of other parts. In this case study, the design of a joint between 3D printed components with a compliant 3D printed mechanism was discussed. This solution proved to be though, stable, cheap and modular. The combination of joints arrangements on the component could help customize parts for better efficiency, especially on different geometries. The presented mechanism was made using PLA material and FDM technology. A future development could be a further reduction in the number of linkage parts. This last step should be performed to adopt polymer's 3D printing as replacement for classic mold materials.

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Biographies

Patrich Ferretti is a Ph.D. Student of the Department of Industrial Engineering, at Alma Mater Studiorum University of Bologna. Patrich is involved in 3D Printing applications and FDM related studies. He is now a tutor at the aforementioned university.

Gian Maria Santi is a Researcher of the Department of Industrial Engineering at Alma Mater Studiorum University of Bologna. Gian Maria is involved in Augmented Reality and 3D Printing applications and studies. He is also a tutor at the aforementioned university.

Giulia Alessandri is a Ph.D. Student of the Department of Industrial Engineering at Alma Mater Studiorum University of Bologna. Giulia is a member of IEOM Student Chapters. Her research area is in preoperative surgical planning for the medical field. Her interests are focused on CAD and 3D printing. She is also a tutor at the aforementioned university.

Giulio Galiè is a PhD Student at DIN - Department of Industrial Engineering at Alma Mater Studiorum - University of Bologna. He is involved in the study of issues related to design planning, car design, 3D printing, and the implementation of innovative technologies such as AR/VR within design paths.

Eleonora Guidotti is a Graduate Student of the Department of Industrial Engineering, at Alma Mater Studiorum University of Bologna. Eleonora is focused on Industrial Product Design.