CORSET PRESSURE PADS EVALUATION USING A CAD/CAM METHOD

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Abstract

Pressure pads are small hand-made corset components used for scoliotic curve correction by applying pressure to the body segment. The design and accuracy of these pads can be increased by using modern approaches like CAD modeling and additive manufacturing. The aim of this research was to apply these methods in the pressure pad development process and evaluate the suitability of the designed prototypes. A CAD software SOLIDWORKS was used for the pad design and 2 manufacturing technologies have been selected, specifically FDM and MJF, for the pad production. As for the material of which the pads could be manufactured, PLA, PETG and PA12 have been selected. Abaqus software, using the finite element method, has been chose for the 9 pad prototypes strength calculation, from which 6 have passed the test. It would be appropriate to expand the given research with CAD pressure pads of various optimized designs with different types and densities of infills.

Keywords

pressure pads, orthosis CAD design, orthosis additive manufacturing, multi jet fusion, PA12

Introduction

Pressure pads are a part of individual corsets and are used to correct the scoliotic curve. They are placed from the inside of the corset structure, where they apply the required pressure to the designated place and thus balance the scoliotic deformity. There may be several pressure pads on one corset, depending on the diagnosis and the type of orthosis. Pressure pads are traditionally made by hand from polyethylene, and by their thickness and size, the pressure on the body segment is regulated. The accuracy of the corset pressure pads manufactured traditionally depends solely on the skills of the CPO (Certified Prosthetists Orthotist) [1].

Additive manufacturing can be applied to the process to increase accuracy and the ability to produce pressure pads with complex shapes. Additive manufacturing enables the production of objects with complex shapes that could not be produced by conventional subtractive manufacturing methods [2]. Using these technologies, it is possible to produce individually designed pressure pads from materials suitable for direct contact with the skin and with sufficient mechanical properties.

The aim of this research is to optimize the manufacturing process of corset pressure pads using CAD (Computer Aided Design) software and additive manufacturing. These pads will be designed for production using FDM (Fused Deposition Modeling) and MJF (Multi Jet Fusion) technologies from PLA (polylactic acid), PETG (polyethylene terephthalate glycol) and PA (polyamide) polymers.

Materials and Methods

Additive manufacturing method

FDM technology and PLA and PETG materials were chosen due to their suitability for prosthetic and orthotic device development, and availability [3, 4]. MJF technology makes it possible to produce parts with excellent dimensional accuracy and low porosity. In addition, MJF printing also exhibits the least impact on the environment and human health, enabling the simultaneous production of various patterns and large-scale green production compared to other technologies [5]. The ability of powder 3D printers to print micro-

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and meso-scale features has enabled a wide range of applications with significant improvements over conventional manufacturing methods. These improvements include flexibility in the design of complex structures, the use of different materials within a single design, reduced manufacturing material costs, and the production of customized products on demand [6].

In the MJF type additive manufacturing process (Fig. 1), a thin layer of polymer powder is first applied to the printing surface, which is preheated to a constant temperature. Then, according to the printing requirement, the fixing agent and the detailing agent are applied to the selected areas of the dust layer using the HP (Hewlett-Packard) thermal ink system (print head). Then the printing surface is exposed to an infrared radiation source, which allows the final melting of the powder in selected areas, creating solid objects. Thanks to the huge advantages of the MJF 3D printing method, it is possible to print complex shapes without support, which allows the production of the final product without additional processing [6–8].

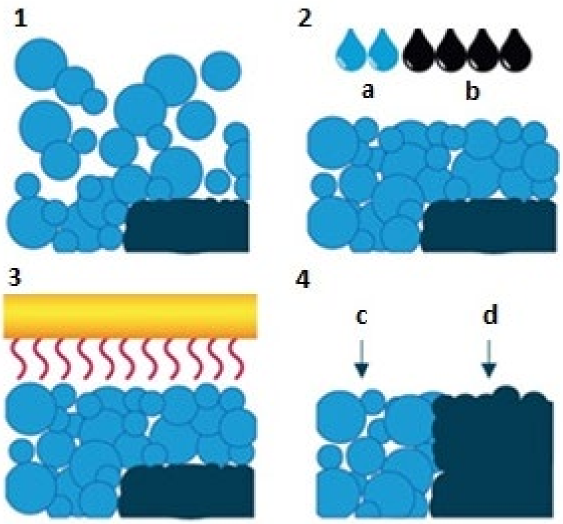

Fig. 1: MJF type additive manufacturing process (1—powder deposition, 2—application of detailing agent [a] and fixing agent [b], 3—exposure to infrared radiation source, 4—powder with detailing agent [c] and solid object [d]).

Polyamide 12 (PA12) is a non-toxic semi-crystalline polymer and is the most used polymer powder for MJF technology. It has excellent impact resistance, good resolution, strong chemical resistance, thermal stability, durability, and the lowest moisture absorption of all polyamides [5]. Products printed from PA12 via MJF technology have tensile and strength moduli comparable to those of injection molded parts and have been successfully adopted in parts for high pressure applications [9, 10]. Since MJF is different from other 3D printing methods, we cannot assume that PA12 printed with MJF technology has the same properties that make it equally biocompatible. Carbon black nanoparticles and triethylene glycol are components of the fixing and detailing agents used in MJF printing and are toxic to cells [5]. However, the material is suitable to produce models that will be in direct contact with the skin, which is ideal to produce prosthetic and orthotic devices, as well as pressure pads [11].

Hudák et al. [1] in their research regarding the measurement of the biomechanical action of pressure pads found that the highest values were measured for pads (P1, P2) with the largest contact surface (from 0 to 100 cm²) and the lowest values are for the pressure pad (P3) and range from 0 to 40 cm². The measurement of pressure values was monitored via pressure sensors on the corset pad-subject interface. Based on the analysis, it was concluded that P3 shows higher average and maximum contact pressures, and P1 and P2 the majority of average contact pressure values, while the range was from 0–0.027 MPa. If extreme values were excluded from the analysis, the average P2 pressures shifted from about 0–0.011 MPa. Clin et al. [12] found in their study that the compression pressures from the pads acting on the torso do not exceed 1 MPa. According to this information, we can determine that the material suitable for 3D printing of pressure pads must have a compressive strength greater than 1 MPa.

Pressure pads prototype design and strength calculation

The prototype of the pressure pad was designed in SOLIDWORKS (Dassault Systèmes, Vélizy-Villacoublay, France) software to represent a simplified version of the pad produced in the traditional way. The size of the pellet was set to 50×50×3 mm with R10 mm edge rounding and "grid" filling. The wall thickness is 1 mm, which is the minimum recommended wall thickness of the model suitable for the given types of 3D printing, and the infill density was set to 3 values: 15%, 7% and 4% (Fig. 2). For these 3 models, a strength calculation was subsequently performed using the finite element method (FEM) in the Abaqus/CAE program (Dassault Systèmes, Vélizy-Villacoublay, France).

Regarding the two planes of geometric symmetry of the CAD models, a 1/4 model was used in the calculation, for which the symmetry conditions for the respective planes were defined. An isotropic homogeneous material was considered during the calculation. An ideal elastic-plastic material model was used to describe the behavior. For the strength calculation of the CAD models, it was necessary to enter certain mechanical characteristics of the selected materials (Table 1) and establish the boundary conditions (Table 2) shown in Fig. 3. A load of 1 MPa was subsequently applied to the top surface of the pad model (Fig. 4) and the calculation procedure was defined as a static non-linear calculation (Static, General, Non-linear) in the program. C3D10HS

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(Shape: Tetra, Order: Quadratic) was selected as the mesh type of CAD model elements, with an average size of elements of 0.5 mm and a free meshing technique.

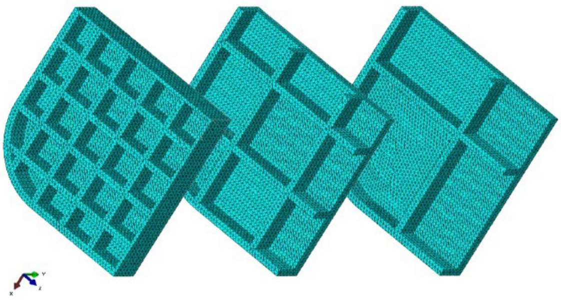

Fig. 2: Pressure pads and representation of its infill density (from left: 15%, 7%, 4%).

Table 1: Mechanical characteristics of the chosen materials [13].

Material	Young moduli (MPa)	Poisson number (–)	Yield strength (MPa)
PA12	1500	0.387	31.7
PLA	2300	0.36	48
PETG	2100	0.4	48

Table 2: Boundary conditions.

Number	Boundary conditions	
1	YZ plane symmetry	U1 = 0
2	XY plane symmetry	U2 = 0
3	Bottom model	U3 = 0

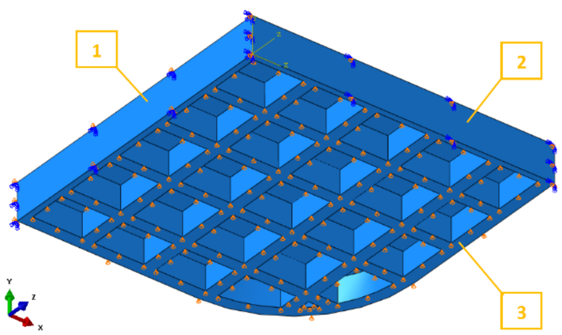

Fig. 3: Boundary conditions applied on the CAD model of the pad.

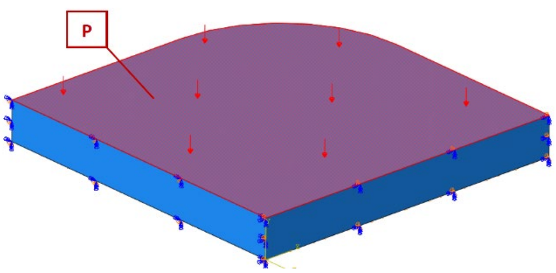

Fig. 4: Load "P" applied on the CAD model of the pad.

Results

Strength calculation results

The result of the strength calculation is the maximum reduced von Mises stress (MPa) and the determination of the exceeding of the yield point (plastic deformation) for the given CAD models from individual selected materials (Table 3). In the pictures Fig. 5, Fig. 6 and Fig. 7 show the fields of reduced stresses caused by the prescribed load. The gray regions correspond to the plastic deformation regions where the stress has exceeded the yield stress.

Table 3: The result of the strength calculation for the given CAD models from individual selected materials.

Material	Pad	Max. reduced von Mises stress (MPa)	Plastic deformation
PA12	1	4.7	No
	2	25.9	No
	3	> 31.7	Yes
PLA	1	4.7	No
	2	26.8	No
	3	> 48.0	Yes
PETG	1	4.7	No
	2	25.6	No
	3	> 48	Yes

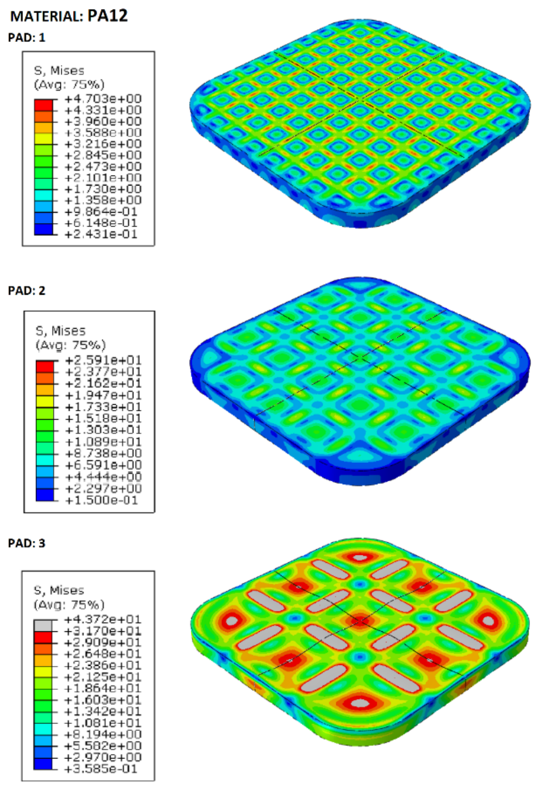

Fig. 5: Test results of Pad 1, 2, 3 made of PA12 material.

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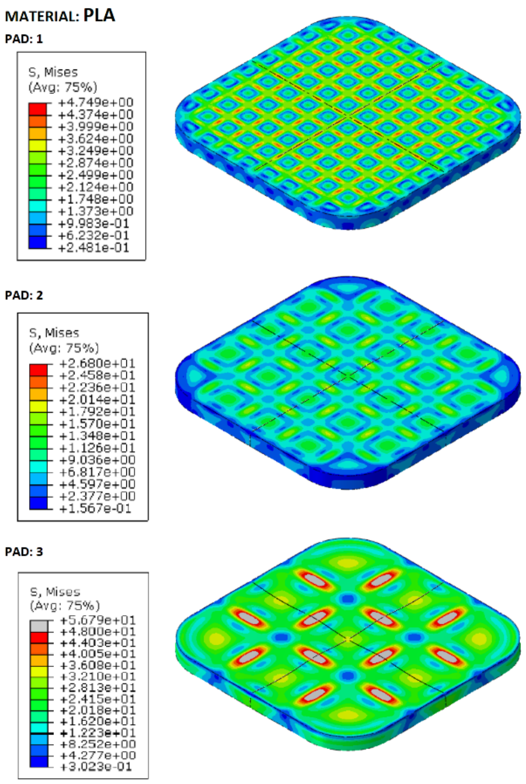

Fig. 6: Test results of Pad 1, 2, 3 made of PLA material.

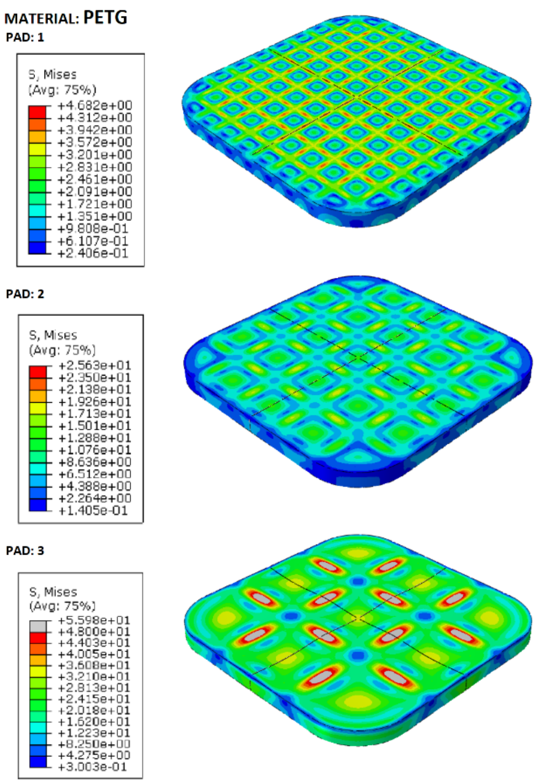

Fig. 7: Test results of Pad 1, 2, 3 made of PETG material.

It is clear from the results that Pad 3 with a filling density of 4% is not suitable for practical application in a corset, as plastic deformations occurred in certain areas under a load of 1 MPa in the selected materials. No plastic deformation occurred with Pads 1 and 2, and the maximum reduced stress values for individual materials are approximately the same (25.6–26.8 MPa).

Discussion and Conclusion

The proposed article analyses the suitability of corset pressure pad CAD design and manufacturing using additive manufacturing technologies. From the results we can state that when designing additively produced corset pressure pads in CAD software, while applying the selected type of model infill and a wall thickness of 1 mm, it is advisable to set the model infill density to 7% or higher. This will ensure the integrity of the model and eliminate the risk of plastic deformations during the use of the torso orthosis on which the pads would be applied.

The design optimalization of prosthetic and orthotic devices using CAD/CAM technologies can be beneficial for future development in this field of research. It is important to approach individually to specific prosthetic and orthotic solutions, because of their original functions. A similar design optimalization process approach may be used, but the use of technologies and materials may vary.

In the future, it would be appropriate to expand the given research with CAD pressure pads of various optimized designs with different types and densities of infills.

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