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Mechanical Strength Analysis of Endoscopic Gastroscope Tip Jackets: 3D Modeling, Computational Simulations, and 3D Printing Fabrication

Dr. Pramodkumar Minocha[1], **Dr. Deveshkumar Kothwala**[1], **Dikshita Lodha**[1], **Dhananjaya Shukla**[1], **Tapan Dhimar**[1], **Mansi Manthan Naik**[1]

[1]Meril Medical Innovations Private Limited, Bilakhia House, Survey no.879, Muktanand marg, Chala, Vapi, Dist-Valsad, Gujarat, 396191, India

Abstract

The durability and functionality of endoscopic gastroscope tip jackets in medical applications are critically and specifically dependent on their mechanical compression strength. All the way from conceptualisation to computer simulations to physical production through 3D printing this study covers it all. In order to highly accurately forecast the mechanical behaviour of our gastroscope tip jacket, sophisticated 3D modelling tools were used to produce exact geometry. In order to understand the stress distribution, deformation patterns, and material performance under clinical load circumstances, finite element analysis (FEA) was used to simulate required compression forces. To improve structural integrity, the simulations led the choice of materials and the optimisation of the design.

In order to evaluate and confirm the ouPEEKts of computational analysis, prototypes were manufactured using advanced medical-grade 3D printing technology with surgical constraints. The mechanical characteristics of the 3D models and the 3D printed samples were analyzed by performing compression tests, and these were used for validation with simulation results. The created models and approaches were proven to be highly reliable when the experimental results showed a strong alignment with the computational predictions.

The potential of integrating computational modelling with 3D printing in the design and testing of medical device components is proven by this integrated method. The results put out a plan for making endoscopic treatments safer, highly efficient, and more durable for patients by improving the designs of gastroscope tip jackets.

Keyword: Endoscopic Gastroscope Tip Jackets, Mechanical Compression Strength, 3D Printing, Finite Element Analysis

1. INTRODUCTION

The science of medical device engineering is constantly evolving, inspired by the desire to better the performance, durability, and safety of devices used in clinical applications. Among these, endoscopic gastroscopes perform a key role in diagnostic and therapeutic therapies within the gastrointestinal tract. The tip of the gastroscope, a vital component, requires good mechanical strength to withstand the forces experienced during insertion, navigation, and operation in difficult anatomical situations. Ensuring the longevity and effectiveness of the gastroscope tip jacket is crucial to maintaining device integrity and insuring patient safety during procedures. Mechanical compression strength is a significant element impacting the functioning of gastroscope tip jackets. A sturdy design must balance structural strength with flexibility, allowing the device to negotiate sensitive and changeable anatomical structures without sacrificing its reliability. However, typical design and testing approaches for such components frequently involve costly iterative prototyping and significant trial-and-error processes. These limits underline the need for more efficient and precise ways to maximise design and performance.

This project attempts to address these difficulties by integrating advanced 3D modeling, computer simulations, and modern production technologies such as 3D printing. Utilizing advanced 3D modeling tools, accurate geometries of gastroscope tip jackets were generated to simulate their mechanical behavior under genuine clinical conditions. Finite Element Analysis (FEA) was performed to simulate compression forces, revealing important insights into stress distribution, deformation patterns, and material performance. These models played a vital role in pushing material selection and design changes, ensuring the tip jacket could endure clinical loads while keeping its functional qualities.

To test the computational predictions, prototypes of the optimized designs were built employing high-performance 3D printing technology. This technology not only cut the time and money needed with traditional prototyping but also insured the use of medical-grade materials suited for clinical applications. Compression testing of the 3D-printed prototypes was done to evaluate their mechanical properties and check the accuracy of the computer models. The results indicated strong congruence between the simulated and experimental data, proving the dependability of the given approaches.

By mixing computational and experimental methodologies, this study offers a unique paradigm for optimizing medical device components. The findings underscore the possibilities of integrating simulation-driven design with 3D printing to boost the performance and dependability of gastroscope tip jackets. This technique not only enhances the design process but also offers great advantages in terms of cost-effectiveness, customisation, and rapid prototyping.

This presentation explores the significance of these findings for the broad field of medical device design and engineering. The results underscore the need of combining current simulation tools and additive manufacturing technology in building next-generation medical equipment. The upgraded gastroscope tip jacket designs described in this work provide a step forward in insuring the safety, lifespan, and usability of endoscopic devices, finally adding to better patient outcomes in clinical settings.

MATERIALS AND METHOD

Biocompatible polymers: PLA and PEEK Material:PLA and PEEK Polymers in Endoscopic Gastroscope Tip Jackets Manufacturing: A Mechanical Strength Perspective

Polylactic Acid (PLA) and Polyetheretherketone (PEEK) have found their use in manufacturing medical device components including Endoscopic Gastroscope Tip Jacket as they possess unique mechanical properties and are 3D printable. There is a growing interest in their use for the production of parts like gastroscope tip jackets, guide tubes, or protective casings because they provide customized mechanical performance tailored to specific clinical needs.

PLA in Endoscopic Gastroscope Tip Jackets

Polylactic acid is biodegradable thermoplastic polymer, synthesising from renewable resources, cornstarch, or sugar cane. As such a material possesses excellent rigidity and dimensional stability, they are useful in areas where structural integrity is critical. In the case of Endoscopic Gastroscope Tip Jackets, PLA components benefit from:

1. **High Tensile Strength**: PLA shows tensile strengths ranging from 50 to 70 MPa, making it ideal for load-bearing parts in non-flexible applications.
2. **Stiffness**: With a Young’s modulus of 2.7–16 GPa, PLA provides rigidity, ensuring the durability of parts subjected to moderate compressive forces during endoscopic procedures.
3. **Biocompatibility**: PLA’s ability to degrade into lactic acid makes it safe for temporary or disposable medical applications.

However, PLA’s brittleness can limit its use in components requiring significant flexibility or impact resistance, which is where PEEK becomes advantageous.

PEEK in Endoscopic Gastroscope Tip Jackets

PEEK is a versatile polymer known for its elasticity, abrasion resistance, and durability. Its applications in Endoscopic Gastroscope Tip Jackets focus on parts requiring flexibility and resilience. Key properties include:

1. **High Elastic Modulus:** PEEK exhibits a high elastic modulus (3.6-4.0 GPa), providing exceptional rigidity and dimensional stability under mechanical loads.
2. **Impact Resistance:** PEEK offers superior impact resistance, effectively absorbing dynamic forces and reducing the risk of fractures during repeated mechanical stresses.

3. **Abrasion Resistance:** PEEK demonstrates excellent abrasion resistance, ensuring long-term durability even in high-friction environments, making it ideal for wear-prone components. Comparative Mechanical Strength Analysis

Comparative Mechanical Strength Analysis

The mechanical performance of materials used in Endoscopic Gastroscope Tip Jackets plays a crucial role in ensuring the safety, durability, and functionality of these components during clinical procedures. Polylactic Acid (PLA) and Polyetheretherketone (PEEK) exhibit distinct mechanical properties that prepare them suitable for specific applications within gastroscope tip jackets.

1. **Tensile Strength:** PLA offers a tensile strength ranging from 50-70 MPa, which is adequate for low-stress, non-flexible applications. However, its brittleness restricts its usage in dynamic environments where repeated mechanical loading is expected. PEEK, with a tensile strength of 90-100 MPa, provides significantly higher strength, making it ideal for applications that require resilience under repetitive mechanical loads.
2. **Elastic Modulus:** PLA's Young's modulus, ranging from 2.7 to 16 GPa, provides adequate rigidity for lightweight applications but may suffer deformation under high mechanical stress. In contrast, PEEK's higher elastic modulus (3.6–4.0 GPa) ensures superior rigidity and dimensional stability, enabling it to withstand dynamic mechanical forces in critical structural components.
3. **Impact Resistance:** PLA demonstrates moderate impact resistance, making it suitable for applications not exposed to substantial shock. However, it is limited in environments subjected to repeated dynamic stresses. PEEK, known for its high impact resistance, absorbs dynamic forces and maintains its integrity during mechanical shocks, making it the material of choice for parts subjected to frequent impact.
4. **Abrasion Resistance:** PLA's moderate wear resistance limits its use in high-friction applications, whereas PEEK's exceptional abrasion resistance ensures durability in environments exposed to continuous friction, guaranteeing long-term performance in high-wear conditions.

Applications in Endoscopic Gastroscope Tip Jackets

The distinct mechanical properties of PLA and PEEK influence their specific applications in the manufacturing of Endoscopic Gastroscope Tip Jackets, where the choice of material depends on the clinical demands of the device.

PLA Applications: Due to its biodegradability, cost-effectiveness, and ease of processing, PLA is well-suited for non-critical, disposable components in gastroscope tip jackets. It is ideal for parts such as non-flexible housings, protective covers, and guide tubes. However, the brittleness and relatively lower mechanical strength of PLA make it unsuitable for components exposed to high mechanical forces, repeated sterilization, or dynamic stresses during procedures.

PEEK Applications: PEEK is designed for high-performance, long-lasting components subjected to repetitive mechanical stress and high-temperature sterilization. Its superior mechanical properties high tensile strength, impact resistance, and abrasion resistance make it ideal for reusable gastroscope tip jackets, instrument tips, and other critical components that must endure cyclic loads and wear. PEEK's biocompatibility ensures its safe use in long-term applications, where material integrity is essential.

In conclusion, PLA and PEEK are both valuable materials in the design and manufacturing of Endoscopic Gastroscope Tip Jackets, with PLA being optimal for low-stress, single-use applications and PEEK excelling in high-performance, reusable components that require superior mechanical strength and resistance to impact and abrasion. The strategic use of both materials allows for optimization of device performance and longevity across a range of endoscopic applications.

Designing the 3D Model

Table 1: Standard Size for Mechanical Compression testing specimen

S. No.	Endoscopic Gastroscope Tip Jacket	Dimension of Endoscopic Gastroscope Tip Jacket
1	Length	25 mm
2	OD	19 mm
3	ID	13 mm
4	Thickness	3 mm

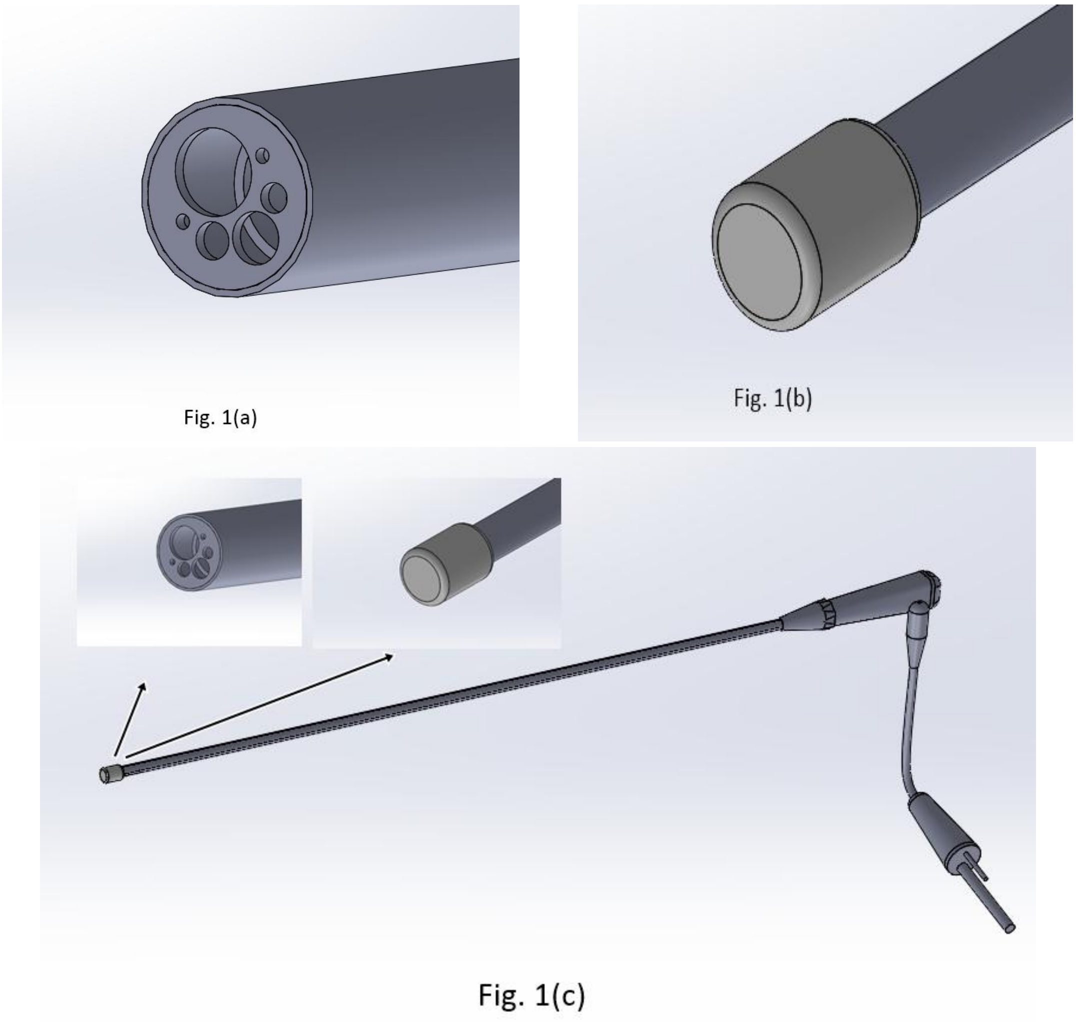


Fig.1. (a), 1(b) and 1(c) Modeling of Endoscopic Gastroscope Tip Jackets

3D Printed Gastroscope Tip Jackets:

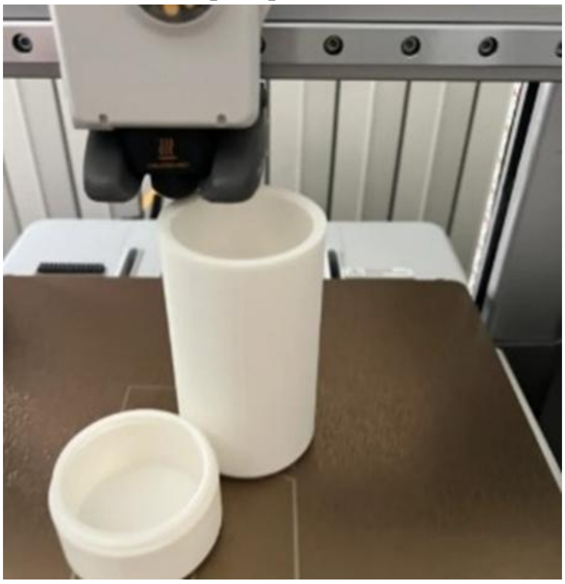


Fig.2. Prototype of Endoscopic Gastroscope Tip Jackets

RESULTS AND DISCUSSION:

The mechanical tensile analysis conducted through Finite Element Analysis (FEA) in Solid works aimed to evaluate the response of the Endoscopic Gastroscope Tip Jacket under compression forces. The following sections present the outcomes of the digital modeling, simulation, and the subsequent evaluation of the results.

Digital Model Creation

The initial step involved the construction of a precise 3D digital model of the polymer PLA and PEEK specimen using SolidWorks CAD tools. This step ensured that the model accurately reflected the geometry and dimensions of the nano fibrous patch material.

Material Assignment

The Polymer PLA and PEEK material was chosen for the Endoscopic Gastroscope Tip Jacket, with its mechanical characteristics such as elasticity and strength defined within the SolidWorks material database. This selection was made based on the desired properties for the device's intended application.

Constraints and Loads

To replicate real-world conditions, constraints and loading conditions were applied to the digital model. The designed prototype's bottom side was fixed, while a Compression load of 5 KN was applied to the top. These conditions were chosen to mimic expected operational scenarios and environmental factors.

Meshing

The digital model was discretized into finite elements through meshing, employing a solid mesh with curvature-based meshing. The mesh had a side length of 1 mm, and Table 2 provides detailed information about the mesh properties.

Table 2: Mesh Properties

S. No.	Properties	Trial Settings
1	Mesh type	Solid Mesh
2	Mesher Used:	Curvature-based mesh
3	Jacobian points for High quality mesh	16 Points
4	Standard element size	10 mm
5	Mesh Quality	High
6	Total Nodes	16894
7	Total Elements	9245
8	Maximum Aspect Ratio	696.12
9	% of elements with Aspect Ratio < 3	9.81
10	Percentage of elements with Aspect Ratio > 10	52.8%
11	Percentage of distorted elements	0
12	Time to complete mesh (hh;mm;ss)	00:00:42

Simulation Setup

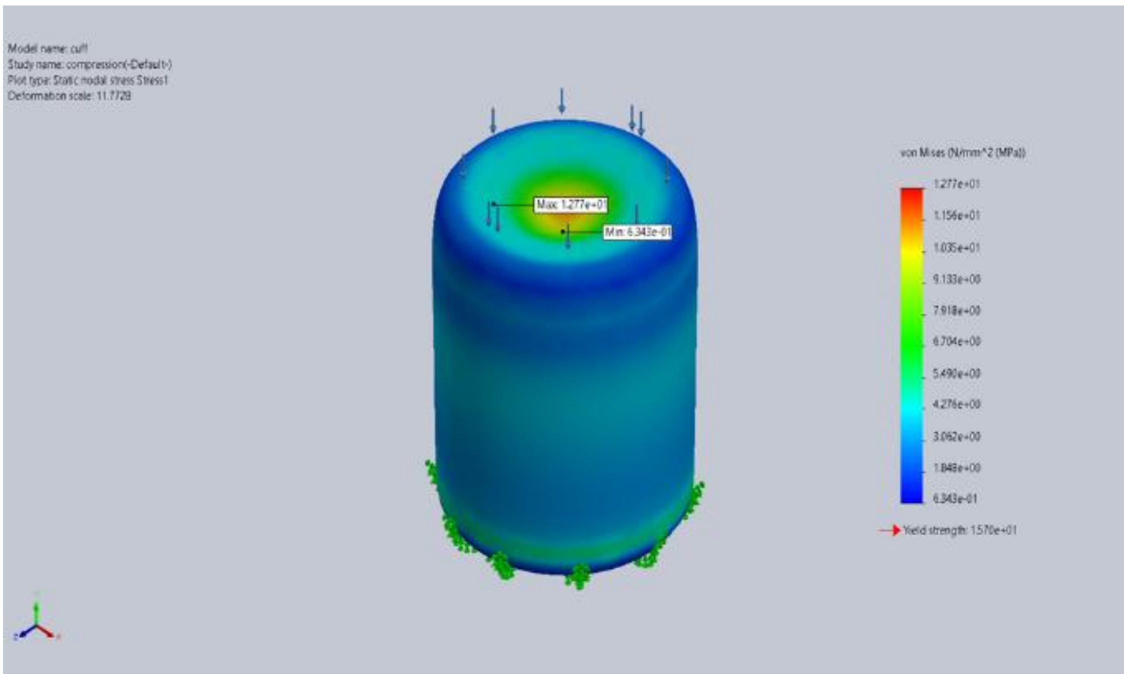
Solid Works Simulation tools were employed to set up the Compression analysis. Parameters such as solver options, convergence criteria, and contact conditions were configured to ensure a precise and efficient simulation.

Analysis Run

The Compression analysis was executed within Solid Works, calculating stress distribution, deformation, and safety factors throughout the polymer PLA and PEEK specimen under the applied Compression forces.

Results Evaluation

The results of the simulation were evaluated to identify regions of high stress, potential deformation, and safety margins. The computational stress analysis, as summarized in Table. 3. and in figure 3(a) and 3(b) accordingly, focused on Von Mises Stress for Compression.



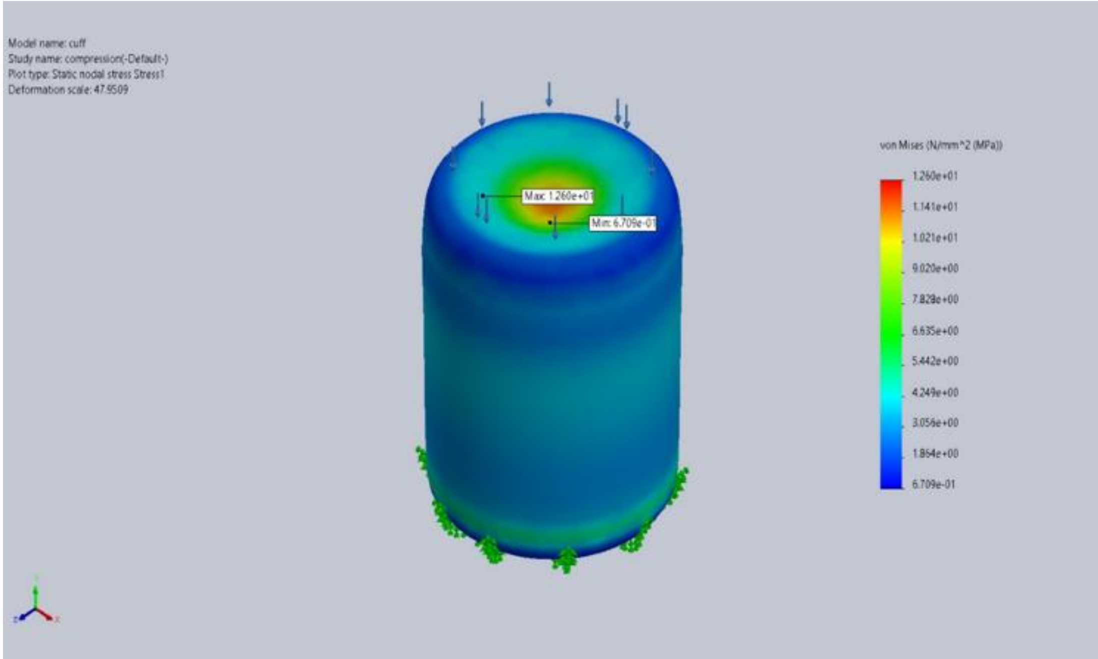


Figure 3. Mechanical Compression Stress Analysis for Endoscopic Gastroscope Tip Jackets [PLA Based tip-3(a), PEEK based Tip-3(b)]

Table. 3. Computational Studies - Mechanical Compression for Endoscopic Gastroscope Tip Jackets

S. No.	Material	Stress Properties	Type	Min	Max
1.	PLA	Compression Stress	Von Mises Stress	$1.277*10^{+1}$ N/mm^2 (MPa)	$6.343*10^{-1}$ N/mm^2 (MPa)
2.	PEEK	Compression Stress	Von Mises Stress	$1.260*10^{+1}$ N/mm^2 (MPa)	$6.709*10^{-1}$ N/mm^2 (MPa)

The compression strength research of endoscopic gastroscope tip jackets revealed considerable differences in mechanical performance between PLA and PEEK materials. Under simulated compression circumstances, the Von Mises stress ranged from 0.634 MPa to 12.77 MPa for PLA, revealing its capacity to sustain moderate stress levels while preserving structural integrity.In the same way, PEEK had a Von Mises stress range of 0.671 MPa to 12.60 MPa, with almost the same maximum strength but a somewhat higher resilience at lower stress levels. These results suggest that PEEK has a bit higher bending resistance, which could make it an attractive alternative for usage that need long-lasting materials. However, PLA's ability to perform within clinically essential stress restrictions suggests that it could be deployed as a biodegradable, cost-effective substitute for gastroscope tip jackets. The results illustrate how vital it is to choose the suitable material when making endoscopic device parts that work well mechanically and satisfy the needs of specific applications.

CONCLUSION

In conclusion, this study shows a complete way for checking the mechanical strength of endoscopic gastroscope tip jackets by combining 3D modelling, computer simulations, and 3D printing materials. Using Finite Element Analysis (FEA), we were able to correctly predict how stress would be distributed and how well the material would work. This helped us with the concept and choice of materials. Advanced 3D printing technologies made it easy to test models, and the results of the studies were very close to what was expected, showing that the methods were reliable.

The dual-material method, combining PLA for its stiffness and PEEK for flexibility, shows the possibility for tailored designs that meet the diverse mechanical demands of clinical applications. This method not only improves the durability and functionality of gastroscope tip jackets but also stresses the benefits of combining simulation-driven design with additive manufacturing. The results show how these technologies can optimize performance while reducing development time and costs.

Ultimately, the optimized designs for gastroscope tip jackets increase the safety, performance, and longevity of endoscopic devices, adding to better patient outcomes. This study provides a strong basis for future innovations in medical device engineering, underlining the importance of integrating computational modeling and advanced manufacturing techniques to address the dynamic challenges of clinical applications.

REFERENCES

[1] Bergström, J.S. and Hayman, D., 2016. An overview of mechanical properties and material modeling of polylactide (PLA) for medical applications. Annals of biomedical engineering, 44, pp.330-340. https://doi.org/10.1007/s10439-015-1455-8

[2] M'Bengue, M.S., Mesnard, T., Chai, F., Maton, M., Gaucher, V., Tabary, N., García-Fernandez, M.J., Sobocinski, J., Martel, B. and Blanchemain, N., 2023. Evaluation of a medical grade thermoplastic polyurethane for the manufacture of an implantable medical device: the impact of FDM 3D-printing and gamma sterilization. Pharmaceutics, 15(2), p.456. https://doi.org/10.3390/pharmaceutics15020456

[3] Aedla, M., Cheng, C.J., Zhou, A.Y., Zhang, S., Hsu, J., Hu, K., Qian, J.C., Sompel, K.V.D., Ho, A., Sharma, K.V. and Logsdon, E.A., 2024. Design and Evaluation of a Spoke-Based Double-Lumen Pediatric Gastrostomy Tube. Children, 11(2), p.263. https://doi.org/10.3390/children11020263

[4] Arun Kumar, P., 2020. EcoDesign for medical devices: Barriers and opportunities to eco effective design of medical devices (Doctoral dissertation, Royal College of Art).

[5] Carvalho, A.D.D.R., Karanth, N. and Desai, V., 2021. Design and characterization of a pneumatic muscle actuator with novel end-fittings for medical assistive applications. Sensors and Actuators A: Physical, 331, p.112877. https://doi.org/10.1016/j.sna.2021.112877

[6] Monaco, E.A., Reed, T., Lynn, T.J., Rimini, S.A., Patel, A.A., Monaco, S.E. and Patterson, B.S., 2024. Practical applications of three-dimensional printing for process improvement in the cytopathology laboratory. Cancer Cytopathology, 132(2), pp.75-83. https://doi.org/10.1002/cncy.22736

[7] Meram, A. and Sözen, B., 2023. Experimental investigation on the effect of printing parameters on the impact response of thin-walled tubes produced by additive manufacturing method. International Journal of Crashworthiness, 28(1), pp.32-45. https://doi.org/10.1080/13588265.2022.2045824

[8] León-Calero, M., Reyburn Valés, S.C., Marcos-Fernández, Á. and Rodríguez-Hernandez, J., 2021. 3D printing of thermoplastic elastomers: Role of the chemical composition and printing parameters in the production of parts with controlled energy absorption and damping capacity. Polymers, 13(20), p.3551. https://doi.org/10.3390/polym13203551

[9] Dahan, N., 2013. The application of PEEK to the packaging of implantable electronic devices (Doctoral dissertation, UCL (University College London)).

[10] Profitiliotis, T., Koltsakidis, S., Tsongas, K. and Tzetzis, D., 2024. Innovative Design of a 3D Printed Esophageal Stent Inspired by Nature: Mitigating Migration Challenges in Palliative Esophageal Cancer Therapy. Biomimetics, 9(6), p.359. https://doi.org/10.3390/biomimetics9060359

[11] Pathak, V. (2023). Computational Studies on Reaction Dynamics of Atmospheric Molecules. International Journal of Innovations in Science, Engineering And Management, 2(3), 105-155. https://doi.org/10.69968/ijisem.2023v2i3150-155

[12] Maharana, T., Sutar, A.K., Routaray, A., Nath, N. and Negi, Y.S., 2014. Polyetheretherketone (PEEK): Applications as a Biomaterial. Encyclopedia of Biomedical Polymers and Polymeric Biomaterials, 35(10), pp.1701-1708.

[13] Zhang, X.Y., Wang, X.Y., Ren, X., Xie, Y.M., Wu, Y., Zhou, Y.Y., Wang, S.L. and Han, C.Z., 2021. A novel type of tubular structure with auxeticity both in radial direction and wall thickness. Thin-Walled Structures, 163, p.107758. https://doi.org/10.1016/j.tws.2021.107758

[14] Kandi, R., Pandey, P.M., Majood, M. and Mohanty, S., 2021. Fabrication and characterization of

customized tubular scaffolds for tracheal tissue engineering by using solvent based 3D printing on predefined template. Rapid Prototyping Journal, 27(2), pp.421-428. https://doi.org/10.1108/RPJ-08-2020-0186

[15] Kranjec, C., Mathew, J.P., Ovchinnikov, K., Fadayomi, I., Yang, Y., Kjos, M. and Li, W.W., 2024. A bacteriocin-based coating strategy to prevent vancomycin-resistant Enterococcus faecium biofilm formation on materials of interest for indwelling medical devices. Biofilm, 8, p.100211. https://doi.org/10.1016/j.bioflm.2024.100211

[16] Merivirta, N., 2017. Improvement of Quality Control of Extruded Tubes With On-Line Optical Measuring Technique (Master's thesis).

[17] Im, S.H., Park, S.J., Chung, J.J., Jung, Y. and Kim, S.H., 2019. Creation of polylactide vascular scaffolds with high compressive strength using a novel melt-tube drawing method. Polymer, 166, pp.130-137. https://doi.org/10.1016/j.polymer.2019.01.067

[18] Bigdeli, A. and Damghani Nouri, M., 2019. Experimental and numerical analysis and multi-objective optimization of quasi-static compressive test on thin-walled cylindrical with internal networking. Mechanics of Advanced Materials and Structures, 26(19), pp.1644-1660. https://doi.org/10.1080/15376494.2018.1444231

[19] Singh, S., Prakash, C. and Ramakrishna, S., 2019. 3D printing of polyether-ether-ketone for biomedical applications. European Polymer Journal, 114, pp.234-248. https://doi.org/10.1016/j.eurpolymj.2019.02.035

[20] Zhang, C., Xiao, S.H., Qin, Q.H. and Wang, H., 2021. Tunable compressive properties of a novel auxetic tubular material with low stress level. Thin-Walled Structures, 164, p.107882. https://doi.org/10.1016/j.tws.2021.107882

[21] Ko, W.J., Song, G.W., Hong, S.P., Kwon, C.I., Hahm, K.B. and Cho, J.Y., 2016. Novel 3D-printing technique for caps to enable tailored therapeutic endoscopy. Digestive Endoscopy, 28(2), pp.131-138. https://doi.org/10.1111/den.12546

[22] Zou, T., Song, Z., Mei, S. and Ou, Y., 2024. Compression properties and energy absorption of Gyroid lattice cylindrical shells filled thin-walled tubes fabricated by selective laser melting. Mechanics of Advanced Materials and Structures, pp.1-13. https://doi.org/10.1080/15376494.2024.2376336