ASEC 2024 Conference

The 5th International Electronic Conference on Applied Sciences

04–06 December 2024 | Online

EXPLORING THE TRADE-OFF BETWEEN PRINTING TIME AND MECHANICAL PROPERTIES: OPTIMIZATION OF THREE-DIMENSIONAL PRINTING CONFIGURATIONS FOR CLINICAL AIDS FABRICATION

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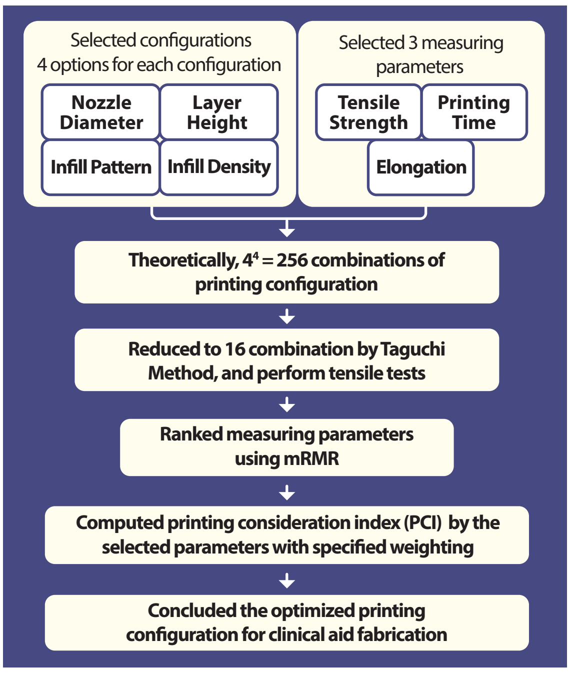
Background and aim(s)

The fabrication of clinical aids using Fused Deposition Modeling (FDM) technology often results in prolonged printing times. Balancing the printing time with the mechanical properties of the printed objects is a critical challenge. This research aims to identify optimized three-dimensional (3D) printing configurations that minimize printing time while maintaining superior tensile strength and elongation properties. The objective of this study is to investigate the intricate relationship between printing time and mechanical properties by analyzing the impact of nozzle diameter, layer height, infill pattern, and infill density on 3D-printed clinical aids. By employing a combination of statistical methods, including Taguchi's orthogonal array design, mRMR (minimum-redundancy maximum-relevancy) feature selection etc, we aim to determine the most influential configurations and their optimal values.



Method

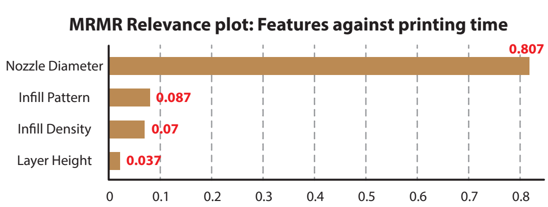
To achieve the research objective, an initial plan of 256 combinations was devised for experimentation. However, utilizing Taguchi's orthogonal array design, the combinations were reduced to 16 trials (T1 - T16), with five samples printed for each trial. The tensile strength test was performed based on the ISO 527–1:20192 standard (with tensile speed: 10 mm/min), and the test samples of Type-A12 in narrow parallel-sided section and tabs with reduced scale based on ISO 20753:2018 standard were prepared for the test. Tensile strength and elongation were evaluated as crucial mechanical properties, while printing time was considered a key time efficiency factor. The mRMR algorithm, a feature selection technique, was employed to identify the parameters with the most significant contribution to the three output factors. A printing consideration index (PCI) was computed with normalized tensile strength, printing time and elongation with weighting of 5:3:2, which was chosen based on careful consideration of the overall objectives and requirements of the clinical aids. Tensile strength is crucial for ensuring the structural integrity and durability of the printed aids, as they need to withstand the forces applied during usage. Printing time, although important for efficiency, was meant to strike a balance between minimizing production time and maintaining acceptable mechanical properties. Elongation, the material's ability to deform without breaking, was considered the flexibility and usability of the 3D-printed clinical aids.

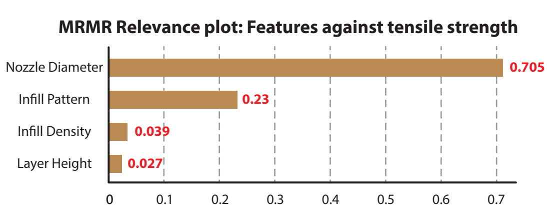
Trial	Layer Height (mm)	Nozzle Diameter (mm)	Infill Density (%)	Infill Pattern	Tensile Strength(MPa)	Elogation Distance (mm)	Printing Time (hr)
T1	0.12	0.20	10	Tri-hexagonal	25.57	5.64	3.07
T2	0.12	0.40	20	Zig-zag	30.39	5.29	1.72
T3	0.12	0.60	30	Cross	34.16	4.83	1.23
T4	0.12	0.80	40	Gyroid	25.93	5.47	0.93
T5	0.16	0.20	20	Cross	29.51	6.12	2.43
T6	0.16	0.40	10	Gyroid	21.72	7.34	1.25
T7	0.16	0.60	40	Tri-hexagonal	33.15	5.15	0.94
T8	0.16	0.80	30	Zig-zag	25.98	5.73	0.71
T9	0.20	0.20	30	Gyroid	29.13	5.64	2.09
T10	0.20	0.40	40	Cross	24.08	6.56	1.20
T11	0.20	0.60	10	Zig-zag	32.74	5.18	0.73
T12	0.20	0.80	20	Tri-hexagonal	29.20	5.87	0.55
T13	0.24	0.20	40	Zig-zag	28.48	6.90	1.72
T14	0.24	0.40	30	Tri-hexagonal	24.89	4.88	0.89
T15	0.24	0.60	20	Gyroid	32.49	5.44	0.60
T16	0.24	0.80	10	Cross	24.05	5.34	0.45

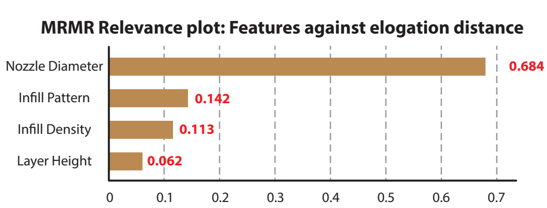
Trial	Layer Height (mm)	Nozzle Diameter (mm)	Infill Density (%)	Infill Pattern	Tensile Strength(MPa)	Elogation Distance (mm)	Printing Time (hr)
A1	0.12	0.60	10.00	Zig-zag	36.61	4.97	1.15
A2	0.12	0.60	20.00	Zig-zag	37.10	4.89	1.32
A3	0.12	0.60	30.00	Zig-zag	39.04	5.58	1.33
A4	0.12	0.60	40.00	Zig-zag	40.51	5.73	1.26
A5	0.16	0.60	10.00	Zig-zag	37.04	5.21	0.87
A6	0.16	0.60	20.00	Zig-zag	30.62	5.36	0.90
A7	0.16	0.60	30.00	Zig-zag	37.50	5.58	0.92
A8	0.16	0.60	40.00	Zig-zag	37.85	5.70	0.94
A9	0.20	0.60	10.00	Zig-zag	31.93	4.90	0.73
A10	0.20	0.60	20.00	Zig-zag	35.01	5.35	0.74
A11	0.20	0.60	30.00	Zig-zag	35.27	5.64	0.77
A12	0.20	0.60	40.00	Zig-zag	38.05	6.11	0.79
A13	0.24	0.60	10.00	Zig-zag	32.05	5.05	0.78
A14	0.24	0.60	20.00	Zig-zag	34.78	5.32	0.60
A15	0.24	0.60	30.00	Zig-zag	35.90	6.22	0.62
A16	0.24	0.60	40.00	Zig-zag	33.36	6.30	0.63

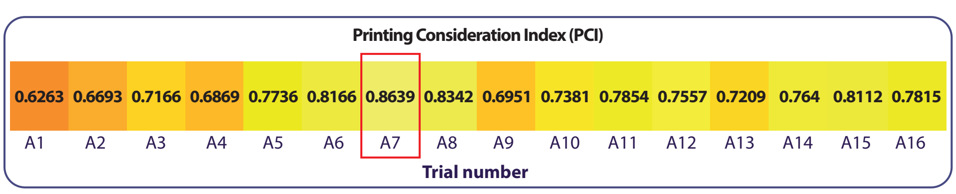
Results

The mRMR analysis revealed a prominent trade-off between printing time and mechanical properties, with the nozzle diameter and infill pattern emerging as the most dominant factors. Specifically, a 0.6mm nozzle diameter and the zigzag infill pattern exhibited the greatest influence on both mechanical properties and printing time. Consequently, these configurations were fixed, while the remaining combinations were printed to obtain an additional 16 trials (A1 - A16). The result of additional trials showed that the highest PCI = 0.8639 in trial 7, which is configured 0.16mm in layer height and 30% infill density.









Conclusion

This research provides valuable insights into the delicate balance between printing time and mechanical properties in 3D-printed clinical aids. By employing a systematic approach that integrates Taguchi's orthogonal array design, mRMR feature selection etc, we identified the 0.6mm nozzle diameter and zigzag infill pattern as the most influential factors affecting both printing time and mechanical properties. The combination of a 0.16mm layer height, 30% infill density, 0.6mm nozzle diameter, and zigzag infill pattern demonstrated superior performance in terms of tensile strength, elongation, and printing time. Understanding these optimized printing parameters will facilitate the production of clinical aids with reduced printing times while preserving high mechanical properties, leading to enhanced efficiency and effectiveness in the field of rehabilitation engineering.