International Journal of Engineering Research & Management Technology
(Peer-Reviewed, Open Access, Fully Refereed International Journal) ISSN: 2348-4039
Volume 11, Issue-4 July-August- 2024 Impact Factor: 7.09
Email: editor@ijermt.org www.ijermt.org

ENHANCING MECHANICAL PERFORMANCE WITH PARAMETRIC OPTIMIZATION IN ADDITIVE MANUFACTURING

Author name : Biduyt Bhadra
Guide name : Dr.Hari Prasad
Subject : Manufacturing and automation
University name : MDU Rohtak (Maharshi Dayanand University Rohtak)

Abstract

This study examines what Flash Forge Guider II 3D printer process parameters mean for ABS example flexural strength. Layer level, raster width, point, and direction point are examined. Utilizing Taguchi procedures, ANOVA, and crossover GA-RSM, the investigation discovers that Raster Point is the main component in flexural strength. ANOVA showed that Raster Point had the best impact with a P-worth of 0.008 and F-worth of 9.15. The GA-RSM streamlining yielded the best flexural strength of 33.096 MPa at 0.25 mm layer level, 0.433 mm raster width, 44.870º raster point, and 29.990º direction point. The study indicated that Layer Height had no influence, while Raster Width and Orientation Angle did. The GA-RSM approach optimized flexural strength better than RSM and Taguchi methods, demonstrating its superiority in fine-tuning process parameters for additive manufacturing success.

Keywords: *Additive Manufacturing, 3D Printing, Flexural Strength, ABS Polymer, Flash Forge Guider II, Process Optimization, Genetic Algorithm.*

1. INTRODUCTION

The invention of additive manufacturing (AM), more popularly referred to as 3D printing, has brought about a revolution in the production of complicated components across a wide range of industries. This is because it has made it possible to create sophisticated geometries that are difficult to achieve using conventional manufacturing techniques. Even though it has many benefits, the mechanical performance of objects that have been created using 3D printing can frequently vary dramatically due to the influence of a number of different process parameters. Optimizing these parameters in order to improve the mechanical qualities of the components that are generated is absolutely necessary in order to make the most of the additive manufacturing process and realize its full potential.

Changing significant cycle factors in additive manufacturing, for example, layer level, raster width, raster point, and direction point, to enhance the presentation qualities of the finished result is implied by the expression "parametric streamlining." The strength, sturdiness, and generally speaking nature of the printed parts not set in stone by these attributes, which assume a critical part simultaneously. Layer height has an effect on the vertical resolution and surface polish, raster width has an effect on the bonding between layers, raster angle has an effect on the alignment of the material deposition, and orientation angle determines how the part is oriented within the build platform.

Researchers and engineers are able to systematically study and adjust these factors in order to produce superior mechanical performance. This is made possible by the utilization of advanced optimization techniques such as Taguchi methods, Response Surface Methods (RSM), and Genetic Algorithms (GA). The purpose of parametric optimization is to determine the ideal combination of process settings that will maximize desirable qualities, such as tensile strength, flexural strength, and impact resistance, while simultaneously decreasing flaws and variability.

- **Importance of Process Parameters in Additive Manufacturing**

Significant cycle factors in additive manufacturing, for example, layer level, raster width, raster point, and direction point, significantly affect the mechanical exhibition of the end result. The difference between the bonding between layers is determined by the raster width, whereas the vertical resolution and surface finish are influenced by the layer height. The orientation angle defines the position of the part within the build platform, while the raster angle has an effect on the alignment of the material deposition. It is the responsibility of each parameter to play a significant part in determining the attributes of the printed parts, including their tensile strength, flexural strength, and general durability.

- **Advanced Optimization Techniques**

Enhanced mechanical performance can be achieved by the utilization of sophisticated optimization techniques, which involve the methodical examination and refinement of process parameters. The identification of the ideal values for these parameters is accomplished by the utilization of techniques such as Taguchi methods, Response Surface Methods (RSM), and Genetic Algorithms (GA). In order to maximize desirable qualities while simultaneously decreasing faults and variability, several strategies are helpful. Researchers and engineers are able to create higher mechanical qualities in 3D-printed components by employing these complex methodologies, which ultimately results in an improvement in the dependability and application of additive manufacturing technologies.

2. LITERATURE REVIEW

Li, S., et.al., (2020). A revolution in product life cycle performance has been brought about by the adoption of additive manufacturing (AM) by high-value-added sectors. This revolution has brought about beneficial design topology as well as functional advancements. When compared to traditional production techniques like tooling and molding, additive manufacturing (AM) typically imposes design constraints on the product. These limitations normally incorporate help structures, building direction (BD), feedstock material characteristics, and some cycle parameters. During the time spent planning and manufacturing AM-driven items, these new components should be thought about. In this review, an AM-driven geography enhancement strategy is proposed, alongside a transitionally isotropic material model and solid anisotropic material with penalization (SAMP). The motivation behind this strategy is to lay out a quantitative connection between interaction related parameters and the mechanical properties of written words. Besides, this connection is executed for cycle and geography enhancement through an inclination-based calculation. More specifically, the direction change lattice is joined with the dynamically isotropic solidness and strength of the written word through the usage of stereolithography apparatus (SLA) to give a depiction of the versatile grid under different BDs. From that point onward, case-subordinate item exhibitions are concentrated on utilizing a coordinated technique that thinks about the general impact of underlying model and BD.

Wang, C., et.al., (2020). Initially, a notion based on parameters is suggested to produce a group of parameterized lattice microstructures with comparable topological characteristics. To achieve a balance between computational efficiency and structural performance, we build a model called (PILM) and introduce two additional design variables into the mathematical formulation. Rather than employing the pseudo-density found in the (SIMP) model, the relative density variable is utilized at the macroscale to characterize the material volume fraction in the design domain. Every microelement is thought of as a distinct microstructure at the microscale, managed by an aspect ratio variable. By inserting the successful flexible frameworks of a few regular microstructure unit cells, one can decide the same properties of parameterized grid microstructures without doing expensive iterative homogenization calculations all through the improvement cycle. Subsequently, for a computational expense that is sensible, the multiscale simultaneous plan method may at the same time upgrade the plainly visible conveyance and their spatially factor microstructural setups. A number of numerical examples are provided to show how successful the suggested method is.

Druzgalski, C. L., et.al., (2020). It is possible to fabricate intricate designs that are challenging to produce using traditional methods thanks to additive manufacturing (AM). Laser powder bed fusion (LPBF) produced metal components can exhibit desirable mechanical qualities and complex design elements. However, in order to remove flaws, enhance dimensional accuracy, and boost repeatability, printing a part that is suitable for its intended application frequently necessitates reproducing and rejecting a large number of pieces. The process of producing functioning LPBF manufactured parts takes longer and costs more money as iteratively converges on the right construction parameters. A versatile and quick system for part-scale process enhancement of erratic calculations is introduced in this research. The computational procedure consolidates results from reenactment-based feed forward control models and use highlight extraction to recognize examine vectors that require parameter adaption. This procedure robotizes the exchange of enhancement strategies to new part plans and offers a framework for effectively streamlining confounded parts through the designated utilization of models with changing levels of authenticity.

3. RESEARCH METHODOLOGY

3.1.Printing Materials and Machines for Additive Manufacturing

A FFB Guider II 3D printer was utilized to print the examples for this review. The printer can make parts with an exactness of ±0.2 mm and has a form envelope estimating. The parts in this study are made of ABS, the most generally utilized 3D printing material. The chemical formula for the widely used thermoplastic ABS is C8H8• C4H6• C3H3N. Styrene, acrylonitrile, and polybutadiene are copolymerized to form ABS.

3.2.Experimental Design

This study assesses and refines the connection between these elements and the proposed reaction qualities by thinking about four principal settings for the Flash Forge Guider II 3D printer. Direction point, raster width, raster point, and layer level were some of the information sources that were ultimately selected. After being expelled from the spout tip, the stored layer's level is calculated along the Z-hub; this is also known as the layer level or the upward direction of the FDM machine. It is usually not the exact diameter of the extruder spout tip. The raster's constituent parts, the dabs' width, are defined by the path taken by the extruder device. It is largely determined by the extruder spout tip's diameter. The raster point, like the x-axis of the form stage's pivot, indicates the direction of the material beds. It is the raster example's point as for the X-pivot. The direction point depicts the direction of the part regarding the x-, y-, and z-tomahawks of the FDM machine and the place where the part will be produced within the form stage. The machine's specifications were used to select the input factors, and the other parameters are set to their default settings.

Table 1. The Range of The Process Parameters That Need To Be Regulated.

Process Parameters	Units	Level 1	Level 2	Level 3
Layer height	mm	0.18	0.27	
Raster width	mm	0.4065	0.4365	0.4665
Raster angle	°	0	22.5	45
Orientation angle	°	0	15	30

3.3.Specimen Fabrication

A 3D model of the test example was made involving CATIA V5 programming as per the directions. The computer aided design record is saved in a sound system lithography (STL) design. The slicer gets the document design after which it separates it into the expected number of layers. Printing parameters can likewise be added utilizing the flash print cutting application. The slicer then converts the STL file to G-code, which the printers then use to start layer-by-layer constructing the model. In accordance with the ASTM D790 standard, the flexural examples were created.

3.4.Experimental Producers

The ASTM D790 standard-molded ABS samples were tested for flexural strength using the UNITEK-94100 universal testing machine. Two supports were used to support the test sample from below, as illustrated in Figure 1, while a 5 mm span was used to apply the stress from above. The loading rate throughout the test was 2.54 mm/min, which is equivalent to 0.1 in/min.). Utilizing a stacking pin, a 10N preload was provided in the focal point of the range length to keep the sample from being inexactly situated between the backings and to ensure that the examples were in great contact with the backings. A crack that stretches out from the base to the top breaks the samples when the greatest flexural strength is achieved. At the point when the sample arrived at 5 rate strains, as expected by the standard, the test was halted for those test samples that didn't separate considerably under weighty burden.

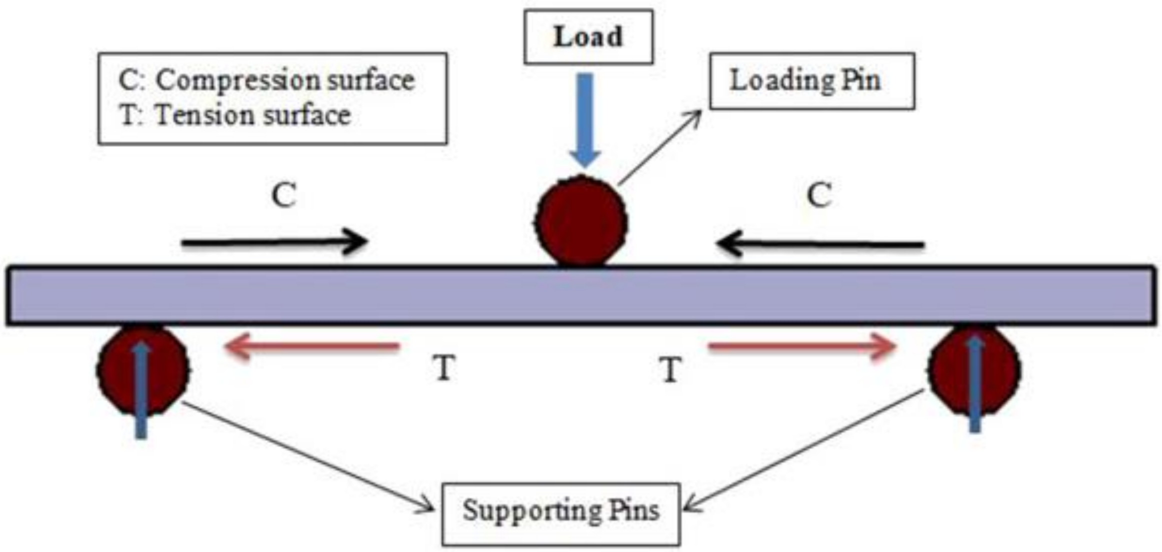

Figure 1. Configuration for flexural test experiment.

4. RESULTS AND DISCUSSION

4.1.Impact Of Process Parameters On Flexural Strength

The aftereffects of flexural strength were examined utilizing the Taguchi examination strategy. The general commitments of a few parameters to the relative varieties in flexural strength are displayed in Table 1. Our outcomes show that raster point is the main element affecting flexural strength, trailed by raster width, direction point, and layer level.

Table 2: The Range Of The Process Parameters That Need To Be Regulated.

Levels	Layer Height (mm)	Raster Width (mm)	Raster Angle (º)	Orientation Angle (º)
1	24.50	22.36	18.45	21.90
2	24.51	27.36	25.65	25.44
3		23.78	25.37	24.12
Delta	0.03	5.03	9.24	1.54
Rank	4	2	1	3

The table shows how different process factors affect a reaction, most likely one that has to do with flexural strength. Raster Angle is the most significant parameter among those that were analyzed; its Delta value of 9.24 indicates that it has a significant impact on the reaction. This parameter plays a crucial role in defining the performance of the material because it dramatically changes the reaction from Level 1 to Level 2 and stabilizes at Level 3. The second most significant element is raster width, which has a Delta of 5.03. Its shift from Level 1 to Level 2 indicates a considerable effect, indicating that, while not as significant as Raster Angle, it still has an impact on the reaction. Orientation angle has a 1.54 delta value, which indicates a moderate influence. Compared to raster angle and raster width, it has a less noticeable effect on the reaction. Finally, with a minimal Delta of 0.03, Layer Height is listed as the least relevant characteristic. The slight difference in Layer Height between the levels suggests that, in relation to the other parameters, it has little effect on the reaction. Overall, this research shows that while changes in Layer Height will have a comparatively minor effect, Raster Angle and Raster Width alterations are likely to have the most effects on the final result.

Table 3. Flexural strength ANOVA.

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Layer height	1	0.003	0.003	0.00	0.995
Raster width	2	81.295	42.147	2.21	0.150
Raster angle	2	327.359	163.679	9.14	0.008
Orientation angle	2	8.342	4.170	0.24	0.795
Error	10	179.055	17.905		

The findings of the ANOVA analysis for flexural strength show that, among the process characteristics examined, raster angle has the greatest impact on flexural strength. Raster Angle is an important factor to take into consideration because of its significant influence on the reaction, as evidenced by the high F-value of 9.14 and the low P-value of 0.008. With a P-value of 0.150 and an F-value of 2.21, Raster Width, on the other hand, has a modest effect on flexural strength. This indicates that, although contributing to variability, its influence is not statistically significant at the traditional 0.05 threshold. Layer Height and Orientation Angle show very high P-values and low F-values, indicating that they have little effect. These findings suggest that flexural strength is not greatly impacted by changes in Layer Height or Orientation Angle. The large error term suggests that the parameters under test are not fully responsible for the significant variability in the response. Raster angle optimization would generally be the most beneficial strategy for increasing flexural strength, but changes to layer height and orientation angle could not have much of an impact.

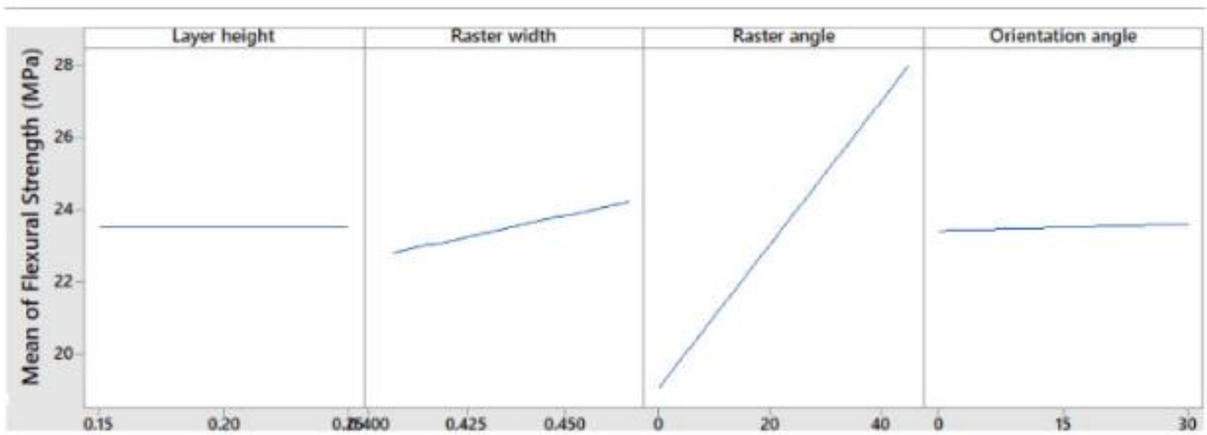

Figure 2: Flexural strength and input parameter factorial graphs.

Figure 2 presents factorial plots illustrating the variation in flexural strength with different input parameters. The flexural strength is almost unaffected by the raster width, orientation angle, or layer height, as shown in these graphs. As the raster angle increases, flexural strength also increases, making it the principal factor affecting flexural strength.

4.2.Hybrid GA-RSM Optimization Results

The hereditary calculation completed in 102 iterations to achieve the most optimal outcome, indicating a highly efficient process. Figure 3 illustrates the typical spread across different ages as a function of the number of iterations. To optimize flexural strength, the data parameters were fine-tuned. It was determined that a raster width of 0.432 mm, a layer height of 0.25 mm, 43.871 raster points, and 29.991 orientation points were the ideal parameters using a multi-objective evolutionary method in MATLAB 2019a. The highest flexural strength achieved was 33.096 MPa with this arrangement. The best values for the flexural strength parameters as calculated by the Taguchi, Genetic Algorithm (GA), and Response Surface Methodology (RSM) algorithms are shown in Table 3. To achieve the maximum flexural strength, the GA-based technique clearly outperformed the RSM and Taguchi approaches when it came to modeling, simulating, and optimizing process parameters.

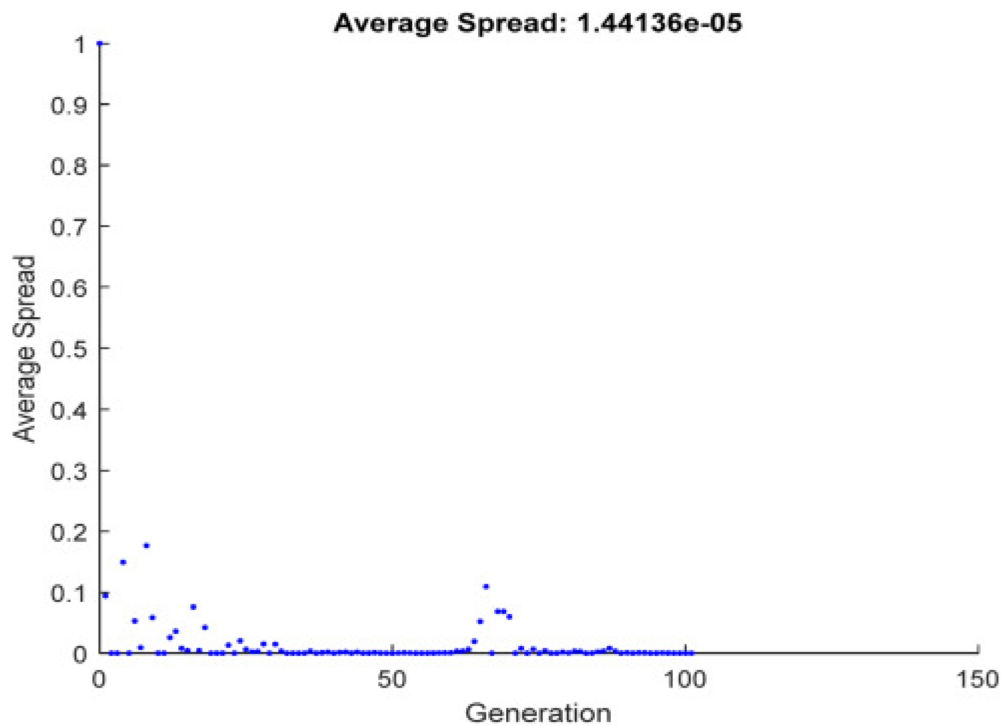

Figure 3. Flexural strength average spread as a function of iteration number.

Table 4. Response parameters were optimized by GA, RSM, and Taguchi techniques.

Optimization Methods	**Layer Height (mm)**	**Raster Width (mm)**	**Raster Angle (˚)**	**Orientation Angle (˚)**	**Optimum Flexural Strength (MPa)**
Hybrid GA-RSM Optimization	0.25	0.432	43.871	29.991	33.096
Response Surface Methods (RSM) Optimization	0.25	0.4306	43.6364	30	33.315

Taguchi Methods Optimization	0.27	0.4165	44	18	32.630

4.3.Taguchi Methods Optimization Results

Three requirements must be met in order to utilize the Taguchi approach and achieve improvement. It is better to be larger, smaller, or nominally preferred. The largest one, flexural strength, was the most appropriate for this investigation. A performance statistic called signal-to-noise ratio (SNR) is employed in the creation of processes and products that are sensitive to noise. The best quality with minimal amount of difference is constantly delivered by choosing process parameters with the most noteworthy sign to-clamor proportion. The best flexural strength esteem in this, not entirely settled by S/N examination, is 32.63 MPa, with a sign to commotion proportion of 30.0047. The best arrangement, not set in stone by Taguchi approaches, are 0.27 mm for layer level, 0.4165 mm for raster width, 44 raster point, and 18 direction points.

5. CONCLUSION

The objective of this research was to determine the effect of process variables on the flexural strength of ABS samples printed using a Flash Forge Guider II 3D printer. Layer level, raster width, raster point, and direction point were among the parameters examined. For optimization, Taguchi techniques, ANOVA, and hybrid GA-RSM were applied. Raster Angle was shown to have the greatest impact on flexural strength, with a Delta value of 9.24, a low P-value of 0.008, and a high F-value of 9.14, according to the analysis. Raster Width had a moderate influence but was not statistically significant, while Layer Height and Orientation Angle had little effect. The hybrid GA-RSM optimization, using parameters of 0.25 mm layer height, 0.432 mm raster width, 43.871° raster angle, and 29.991° orientation angle, produced the greatest flexural strength of 33.096 MPa. Compared to the Taguchi and RSM approaches, which yielded good results but somewhat lower flexural strengths, this strategy was more successful. Overall, flexural strength is greatly increased by maximizing raster width and raster angle. The best method for adjusting these parameters turned out to be the GA-RSM strategy, proving its usefulness in additive manufacturing.

REFERENCES

1. *Cai, C., Wu, X., Liu, W., Zhu, W., Chen, H., Qiu, J. C. D., ... & Shi, Y. (2020). Selective laser melting of near-α titanium alloy Ti-6Al-2Zr-1Mo-1V: Parameter optimization, heat treatment and mechanical performance. Journal of Materials Science & Technology, 57, 51-64.*
2. *Cao, L., Li, J., Hu, J., Liu, H., Wu, Y., & Zhou, Q. (2021). Optimization of surface roughness and dimensional accuracy in LPBF additive manufacturing. Optics & Laser Technology, 142, 107246.*
3. *Chen, S. G., Gao, H. J., Wu, Q., Gao, Z. H., & Zhou, X. (2022). Review on residual stresses in metal additive manufacturing: formation mechanisms, parameter dependencies, prediction and control approaches. Journal of materials research and technology, 17, 2950-2974.*
4. *Dong, G., Tang, Y., Li, D., & Zhao, Y. F. (2020). Design and optimization of solid lattice hybrid structures fabricated by additive manufacturing. Additive Manufacturing, 33, 101116.*
5. *Druzgalski, C. L., Ashby, A., Guss, G., King, W. E., Roehling, T. T., & Matthews, M. J. (2020). Process optimization of complex geometries using feed forward control for laser powder bed fusion additive manufacturing. Additive Manufacturing, 34, 101169.*
6. *El Magri, A., El Mabrouk, K., Vaudreuil, S., Chibane, H., & Touhami, M. E. (2020). Optimization of printing parameters for improvement of mechanical and thermal performances of 3D printed poly (ether ether ketone) parts. Journal of Applied Polymer Science, 137(37), 49087.*
7. *Guanghui, S. H. I., Chengqi, G. U. A. N., Dongliang, Q. U. A. N., Dongtao, W. U., Lei, T. A. N. G., & Tong, G. A. O. (2020). An aerospace bracket designed by thermo-elastic topology optimization and manufactured by additive manufacturing. Chinese Journal of Aeronautics, 33(4), 1252-1259.*
8. *Jihong, Z. H. U., Han, Z. H. O. U., Chuang, W. A. N. G., Lu, Z. H. O. U., Shangqin, Y. U. A. N., & Zhang, W. (2021). A review of topology optimization for additive manufacturing: Status and challenges. Chinese Journal of Aeronautics, 34(1), 91-110.*
9. *Kumar, A., & Maji, K. (2020). Selection of process parameters for near-net shape deposition in wire arc additive manufacturing by genetic algorithm. Journal of Materials Engineering and Performance, 29, 3334-3352.*
10. *Li, S., Yuan, S., Zhu, J., Wang, C., Li, J., & Zhang, W. (2020). Additive manufacturing-driven design optimization: Building direction and structural topology. Additive Manufacturing, 36, 101406.*
11. *Mai, D. S., Doan, T. K., & Paris, H. (2021). Wire and arc additive manufacturing of 308L stainless steel components: Optimization of processing parameters and material properties. Engineering Science and Technology, an International Journal, 24(4), 1015-1026.*

12. *Seede, R., Shoukr, D., Zhang, B., Whitt, A., Gibbons, S., Flater, P., ... & Karaman, I. (2020). An ultra-high strength martensitic steel fabricated using selective laser melting additive manufacturing: Densification, microstructure, and mechanical properties. Acta Materialia, 186, 199-214.*
13. *Shanmugam, V., Rajendran, D. J. J., Babu, K., Rajendran, S., Veerasimman, A., Marimuthu, U., ... & Ramakrishna, S. (2021). The mechanical testing and performance analysis of polymer-fibre composites prepared through the additive manufacturing. Polymer testing, 93, 106925.*
14. *Sheoran, A. J., & Kumar, H. (2020). Fused Deposition modeling process parameters optimization and effect on mechanical properties and part quality: Review and reflection on present research. Materials Today: Proceedings, 21, 1659-1672.*
15. *Wang, C., Gu, X., Zhu, J., Zhou, H., Li, S., & Zhang, W. (2020). Concurrent design of hierarchical structures with three-dimensional parameterized lattice microstructures for additive manufacturing. Structural and Multidisciplinary Optimization, 61, 869-894.*