14th Annual International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), February 12-14, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240140
Published: February 12, 2024

Topology Optimization of Turbine Blade Using Two Types Lattice Structures with Different Parameter

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Abstract

The aerospace and medicinal industries pay close attention to lattice structures. Because they help reduce weight by replacing of the internal solid portion of the blade with different lattice structures. Applying of these technology taking into account for achieving appropriate homogenization between the material, unit cell, and additive manufacturing (AM) technology. Lattice structures with topology optimization have a great potential and flexibility offered to the designers working in the area of designing lightweight structures as well as high strength at the same time compared with solid form structures. The main goal of this paper is to investigate the designing of graded density structures of various lattice designs for dense materials with thermo-mechanical behavior of numerous lattice-based configurations (such as Gyroid and X-cell were applied for a turbine blade. The main goal is for reducing the weight of the turbine blade to achieve the best mechanical, thermal properties.

Keywords
Lattice structure, Gyroid structure, Diamond structure, Additive Manufacturing.

1. Introduction
Many industries, particularly the aerospace and medicinal industries, pay close attention to lattice structures. Because they help reduce weight by replacing of the internal solid portion of the blade with gyroid lattice structures while taking into account achieving appropriate homogenization between the material, unit cell, and AM technique. Therefore, in order to build blades with better end-use properties, it is essential to understand the topological interaction between lattices and the materials that make up their component parts.

2. Literature Review
The manufacture of lightweight lattice structures with complex geometries and the appropriate material compositions is possible using additive manufacturing (AM) techniques was presented by Saleh et al. (2022) and Thompson et al. (2016). These techniques can also be used to create lattice structures that offer a unique set of mechanical, thermal, and optical properties. For example, Shi (2020) tested various structures made by SLM at different densities. They designed and tested Gyroid, Diamond, IW, and Primitive designs of lattice structures for compression effectiveness and energy absorption. Many industries, particularly the aerospace and medicinal industries, pay close attention to lattice structures. Because they help reduce weight and make it easier to manage a component's mechanical and physical characteristics, lattice structures are necessary according to Tang, Yunlong et al. (2015) and Cutolo, Antonio, (2020). Additionally, lattice structures allow for flexibility in design without the need to complete alter the structural shape according to Du, Yuexin et al. (2020) and Yonekura, Kazuo (2023). This is what motivates lattice structures to be used in the production of turbine blades. Irrespective to the method of achieving the desired lattice structure in the material there is an upmost need to maintain the homogeneity in the material and its unit cells arrangement. AM is considered one of those techniques that can maintain the said homogeneity. It can be seen in a study presented by Duan et al. (2020), wherein the authors have employed AM to produce blades having graded lattice structures instead

of fully solid structure. A better set of mechanical and physical properties are reported in case of graded lattie structures as compared with solid structures. In order to build blades with better end-use properties, it is essential to understand the topological interaction between lattices and the materials that make up their component parts Alkebsi, Ebrahim Ahmed et al. (2021). The fundamental difficulty, nevertheless, still lies in selecting the ideal lattice structure. Researchers have proposed three lattice structures as the most effective ones including Gyroid and X-cell.

3. Methodology

The methodology for designing lattice structures varies depending on the specific application. The design involves choosing an appropriate geometry with cell size, shell thickness, lattice thickness, and mesh tolerance as shown in Figure 1.

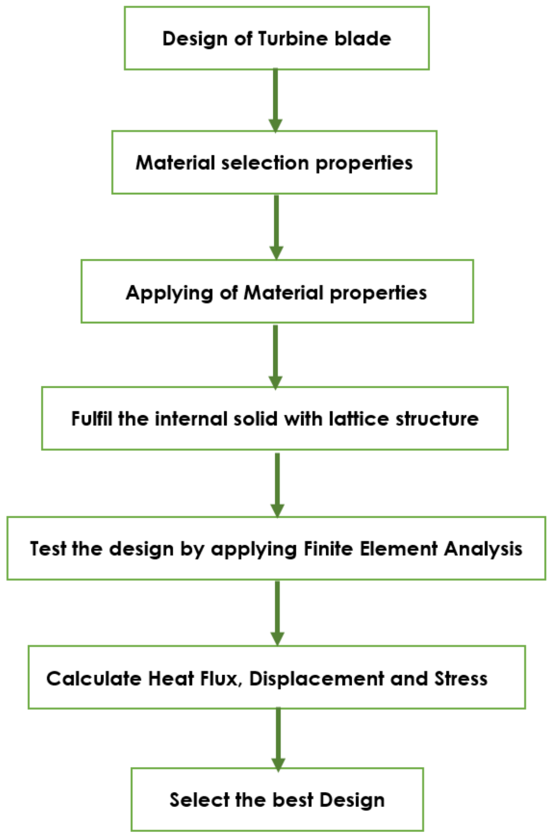
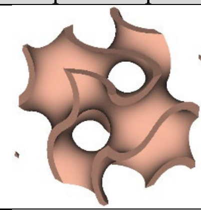


Figure 1. Proposed Methodology of designing of lattice structure

3.1 Design phase

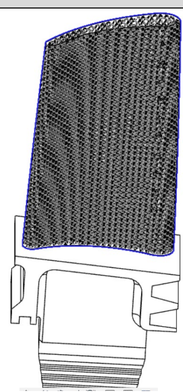
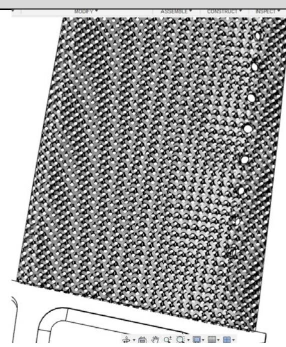
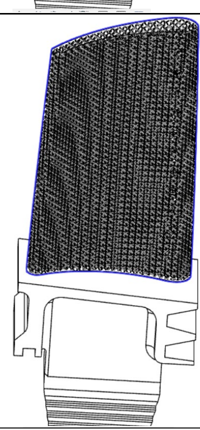
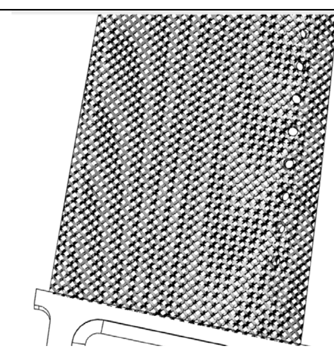
The first step involves the designing of lattice structures having uniformity in the design. The designing is associated with the 3D model of a turbine blade using Autodesk Fusion 360 software as shown in Table 1.

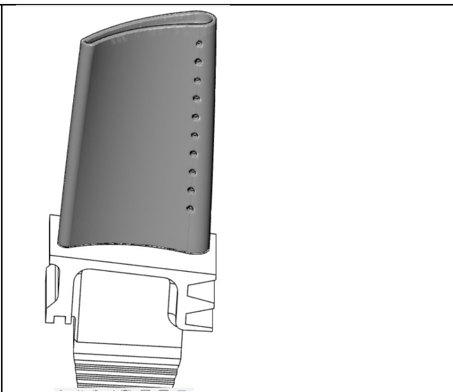
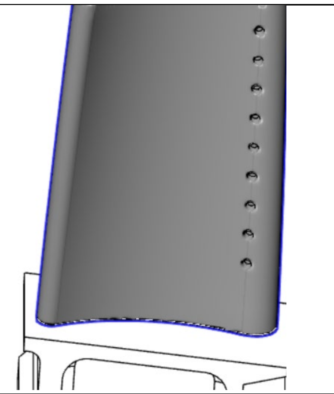
Table 1. The stacking of unit cells in x, y, and z axes of Gyroid and X-Cell lattice as shown in Table

Lattice type	Level-set approximation equation	Graphical representation
Gyroid	sin(x) cos(y) + sin(y) cos(z) + sin(z) cos(x)	
X-Cell	cos(X) + cos(Y) + cos(Z)	

NACA (NACA 2412 (naca2412-il)) data has been used to produce the similar model design with original mass equal to 826.107g for the solid infill of the turbine blade. The reduction of the mass of the gyroid and x-Cell as as hown in Table 2.

Table 2. Design information of gyroid, x-Cell and solid structure of turbine blade.

Structure Type	Wireframe of turbine blade	Inside	Mass of turbine blade
Gyroid Structure			Area = 93916.217 mm^2 Mass = 522.341 g
X-Cell			Area = 92737.311 mm^2 Mass = 495.425 g

Solid Structure			Area = 28319.568 mm^2 Mass = 826.107 g

3.2 Material Properties

According to Nagesh, R., H. R. et al. (2017), the current gas turbines run at about 1370°C, Inconel 718 can withstand a high temperature of 1350°C and other thermal conditions of the gas turbine and the properties of Inconel 718 as shown in Table 3.

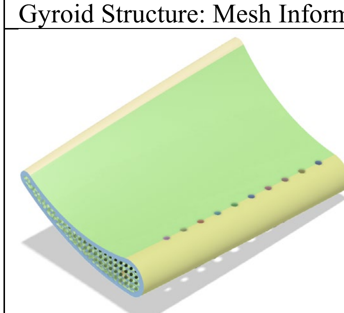
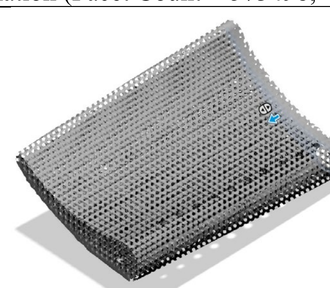
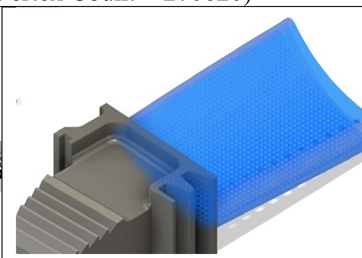
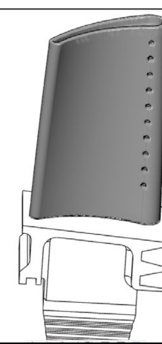
Table 3. Inconel 718: Set of different properties required in case of designing the turbine blades

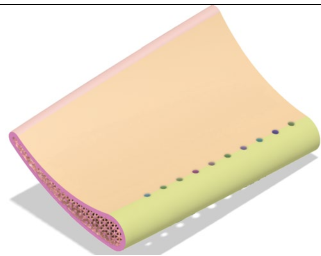
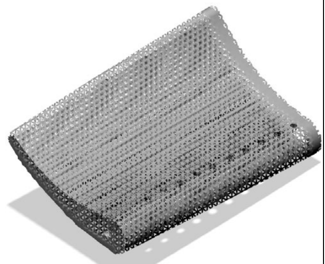
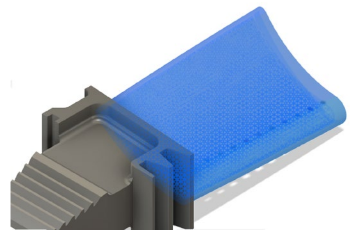
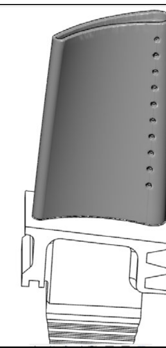
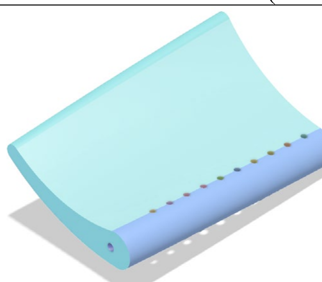
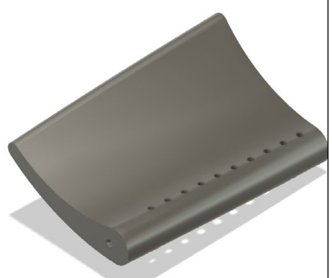
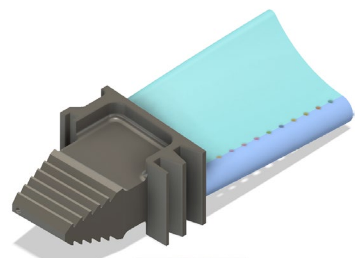
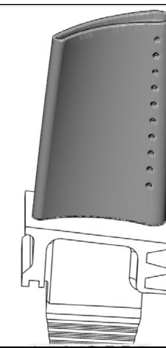
Property	Unit	Value
Density	Kg/m3	8190
Young's Modulus	GPa	200
Ultimate Tensile Strength	MPa (min)	1375
Yield Tensile Strength	MPa	1100
Thermal Conductivity	w/m°K	11.4
Specific Heat	J/Kg°C	435
Capacity Melting Point	°C	120-1336
The Bulk Modulus	MPa	1.375e+5
Shear Modulus	MPa	63,463
Poisson's Ratio		0.3

3.3 Generated Mesh

The mesh consisted of of gyroid, X-Cell and solid structure with an average size of 3 mm is presented in Table 4.

Table 4. The representation of the mesh structure:

Gyroid Structure: Mesh Information (Facet Count = 573498, Vertex Count = 270620)			
			
X-cell Structure: Mesh Information (Facet Count = 535314, Vertex Count = 262220)			

			
Solid: Mesh Information (Facet Count = 26132, Vertex Count = 13026)			
			

3.4 Finite Element Analysis

The preliminary design of the turbine blade is analyzed in terms of its behavior under thermal and mechanical loading conditions using finite element analysis. The steady state of the turbine as shown in Figure 2.

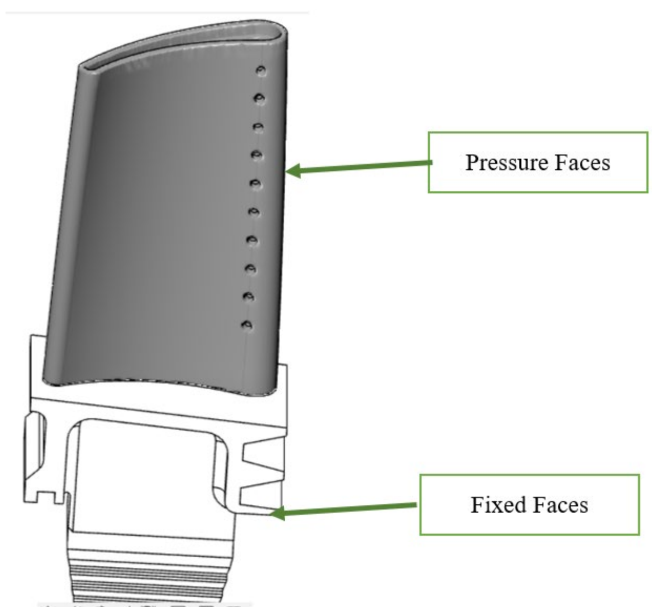
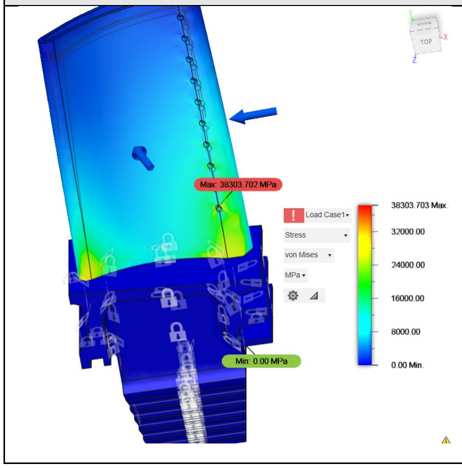
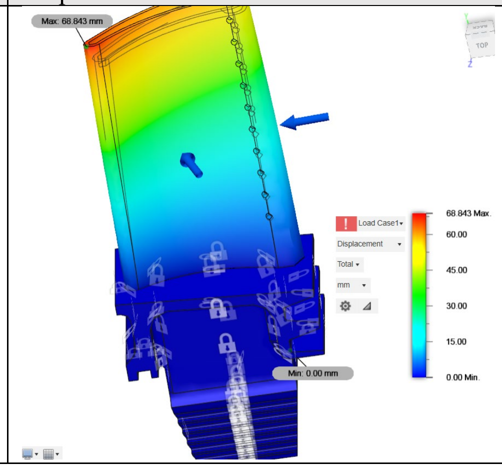
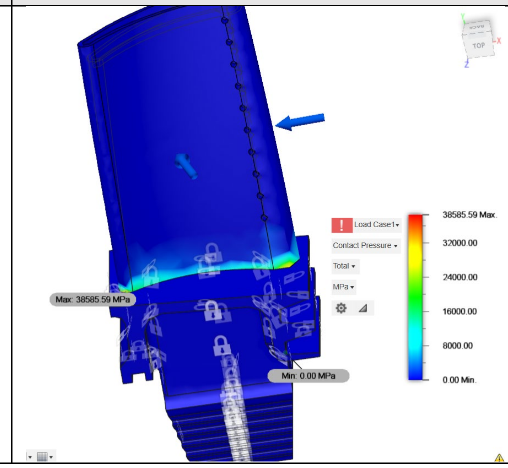


Figure 2. Steady state of turbine blade

The results of the design blade configured through FEA are presented. A comparison between different designs, which were obtained from the last module, is presented as shown in Table 5.
Which represent the Von Mises stress, Displacement, and Pressure.

Table 5. FEA result

Von Mises stress	Displacement	Pressure
		

The FEA result, Total Heat Flux (Max 2.52 X 10^6 W/m2), Stress (Max 38303.702 MPa) and the mechanical deflection in the form of deformation is changed from a value of 0 to a maximum level of 68 mm as shown in Figure 3.

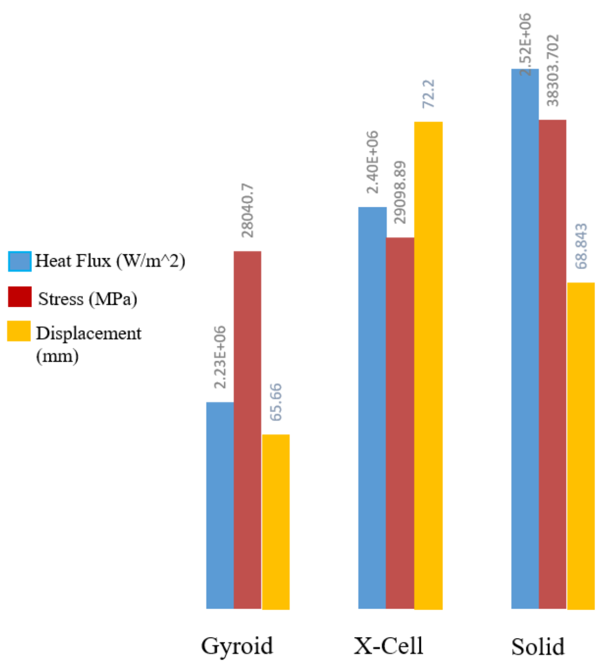


Figure 3. FEA result of Heat Flux, Stress and displacement.

5. Conclusion

The designing and manufacturing of energy efficient turbine blades was presented in this paper. A comparison between different designs, which were obtained , to determine the optimal selection of parameters, which are lattice thickness and cell size has been extensively carried out. It can be conclude as the initial level validation of the proposed designs and their efficacy was presented. Finally, this study illustrate the design parameters for each of the above listed designs, the heat flux values, stress, and displacements analysis by the study of numerical simulations of the suggested lattice structures under the influence of the thermomechanical loads are conducted.

References

Alkebsi, Ebrahim Ahmed A., "Design of graded lattice structures in turbine blades using topology optimization." International Journal of Computer Integrated Manufacturing 34.4: 370-384, 2021.

Cutolo, A., "Mechanical properties of diamond lattice Ti–6Al–4V structures produced by laser powder bed fusion: On the effect of the load direction." Journal of the Mechanical Behavior of Biomedical Materials 104: 103656, 2020.

Du, Y., "Laser additive manufacturing of bio-inspired lattice structure: Forming quality, microstructure and energy absorption behavior." Materials Science and Engineering: A 773: 138857, 2020.

Duan, S., Weibin Wen, and Daining Fang. "Additively-manufactured anisotropic and isotropic 3D plate-lattice materials for enhanced mechanical performance: Simulations & experiments." Acta Materialia 199: 397-412, 2020.

Saleh, M.; Anwar, S.; Al-Ahmari, A.M.; Alfaify, A. Compression Performance and Failure Analysis of 3D-Printed Carbon Fiber/PLA Composite TPMS Lattice Structures. Polymers (Basel). 14, 4595, 2022, doi:10.3390/polym14214595.

Nagesh, R., H. R. Apoorva, and R. Mohan, "Static Structural Analysis of Gas Turbine Blades Comparing the Materials." International Advanced Research Journal in Science, Engineering and Technology (IARJSET) 4 (7): 29–32, 2017. doi:10.17148/IARJSET.

Shi, X.; Liao, W.; Li, P.; Zhang, C.; Liu, T.; Wang, C.; Wu, J. Comparison of Compression Performance and Energy Absorption of Lattice Structures Fabricated by Selective Laser Melting. Adv. Eng. Mater. 22, 1–9, 2020, doi:10.1002/adem.202000453.

Tang, Yunlong, Aidan Kurtz, and Yaoyao Fiona Zhao. "Bidirectional Evolutionary Structural Optimization (BESO) based design method for lattice structure to be fabricated by additive manufacturing." Computer-Aided Design 69: 91-101, 2015.

Thompson, M.K.; Moroni, G.; Vaneker, T.; Fadel, G.; Campbell, R.I.; Gibson, I.; Bernard, A.; Schulz, J.; Graf, P.; Ahuja, B.; et al. Design for Additive Manufacturing: Trends, Opportunities, Considerations, and Constraints. CIRP Ann. - Manuf. Technol, 65, 737–760, 2016, doi:10.1016/j.cirp.2016.05.004.

Yonekura, Kazuo, Hitoshi Hattori, and Takafumi Nishizu. "Fluid topology optimization and additive manufacturing of a liquid atomizer using an extensive number of grid points: Minimizing pressure loss of liquid atomizer." The International Journal of Advanced Manufacturing Technology 126.3-4: 1799-1806, 2023.

Biography

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