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Finite element analysis of anisogrid lattice structures

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Abstract

Anisogrid lattice structures are gaining increasing interest due to their exceptional physical and mechanical properties. Enabled by additive manufacturing techniques, these structures offer high strength-to-weight ratios, making them ideal for lightweight mechanical components. This study aims to develop a finite element model to evaluate the stress distribution in anisogrid lattice structures. A sensitivity analysis was conducted on geometric parameters to identify their influence on the stress state. The results provide valuable preliminary insights into how the geometry of anisogrid lattices can be optimized to enhance their performance and contribute to the design of high-performance, lightweight metamaterials suitable for various engineering applications, including aerospace, automotive and structural fields.

Keywords: anisogrid lattice structures; additive manufacturing; FEM; stresses

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1. Introduction

In recent decades, lattice structures have attracted increasing attention as promising solutions for applications requiring high strength-to-weight ratios, such as aerospace and naval engineering. Among the most interesting lattice topologies are anisogrid structures, that are composite or metallic reticular architectures characterized by anisotropic stiffness properties, achieved through the repetition of an elementary cell.

Anisogrid lattice structures offer outstanding physical and mechanical properties not only through material selection and manufacturing technology, but especially through the design of their cell geometry (Vasiliev, 2001; Morozov et al., 2024). These structures are capable of absorbing large strain energies due to the deformation of the internal grid

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and they demonstrate exceptional mechanical efficiency under axial compressive loads. Their geometry, characterized by intersecting ribs, promotes internal load redistribution, significantly enhancing buckling resistance. These properties make anisogrid structures ideal for load-bearing applications such as rocket fuselages, satellite supports and aircraft panels (Kusni et al., 2024; Nesterov et al., 2025).

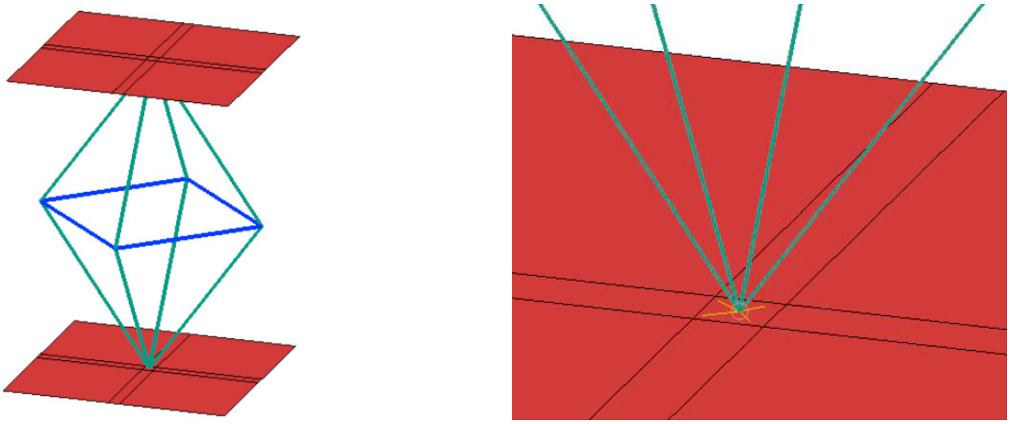
The continued advancement of additive manufacturing technologies has boosted the feasibility of lattice-based designs, enabling the fabrication of complex geometries with relatively low production time and cost. The current challenge is to provide satisfactory mechanical properties with minimum mass. Totaro and Gürdal (2009) proposed a method to optimize composite lattice shell structures by minimizing mass under combined buckling, strength and stiffness constraints. Gentili et al. (2022) experimentally tested composite anisogrid structures made of polyamide reinforced with short carbon fibers and found that the buckling behavior of lattice structures is highly influenced by the geometry of the ribs.

Sandwich structures, consisting of an upper and lower skin and a lattice core, are particularly advantageous in preventing fluid permeation and enhancing mechanical performance. In this configuration, the skins distribute external loads, while the core ribs contribute substantially to stiffness and bending resistance of the whole cell (Fan et al., 2007). Li et al. (2016) investigated the dynamic responses of various sandwich plates under different impact speeds and identified tetrahedral sandwich plate with aluminum foam core as an effective solution for impact energy absorption. Xue and coauthors (2021) studied the influence of panel thickness on the underwater impact resistance of a pyramid lattice structure, focusing on the deflection of the back panel and the energy absorption capability of each component. They found that the front plate primarily affects both deflection and energy absorption. Consequently, the underwater shock resistance of the structure can be effectively improved by appropriately increasing the front panel thickness, without significantly increasing the overall mass per unit area.

This work investigates anisogrid sandwich panels under static compressive loading, focusing on how the geometric parameters of a single elementary cell influence stress distribution for potential application in high-efficiency, lightweight components for aerospace, automotive and structural applications. The results highlight the importance of properly designing both the skins and the ribs.

2. Finite element model

The core of the sandwich panel investigated in this study has an octahedron geometry, identified in the literature as a lattice structure with good crashworthiness properties (Nasrullah et al., 2020). The elementary cell of the sandwich panel was modelled into Abaqus using beam elements for the ribs and shell elements for the upper and lower skins (Fig. 1). The dimensions of the elementary cell are 10 mm x 10 mm x 17 mm. Different diameters for the inclined and horizontal ribs and different skin thicknesses were investigated. The thickness was defined to extend outward from the core to prevent intersections during geometry rendering and to ensure accurate calculation of inertia properties.



a) b)

Fig. 1. Finite element model: (a) assembly; (b) detail of the beam-shell junction.

The anisogrid structure was assumed to be manufactured in AlSi10Mg aluminum alloy powder, which is widely used in selective laser melting due to its good printability, low cost and favorable mechanical properties post heat treatment. The use of a lightweight material such as light alloys enables further mass reduction (Baragetti and Villa, 2015; Baragetti and Arcieri, 2023). The material was modeled as homogeneous, isotropic and linearly elastic, with a Young's modulus of 70 GPa and a Poisson's ratio of 0.34.

To model the interaction between the ribs and skins, the tips of the inclined rib beam elements were positioned to coincide with the center points of the skin surfaces, ensuring a shared node between the ribs and the skins. Additionally, the beam tips were coupled to square partitions on the skin surfaces to distribute the load (Fig. 1b). The connection was simulated using continuum distributing couplings, which average the forces across the coupled nodes to avoid unrealistic stress concentrations at the beam–shell junctions. All the rotational degrees of freedom were constrained. The size of each square partition was set equal to the diameter of the inclined ribs to ensure consistent contact behavior.

A static general analysis was performed, with nonlinear geometry effects activated. A constant pressure of 0.5 MPa was applied on the upper skin. All the edges of the lower skin were fixed.

A mesh sensitivity analysis was conducted by progressively refining the mesh size and evaluating stress convergence for a reference loading case. A final mesh size of 0.25 mm was selected, as it was demonstrated to ensure numerical accuracy without excessive computational cost.

This study preliminary investigates the influence of the diameter of the ribs, both inclined and horizontal, and the skin thickness. For this reason, the investigated parameters were varied according to L9(3^4) Taguchi array (Condra, 1993) in order to run only nine finite element simulations to investigate the effects of the parameters, similarly to the approach used by Arcieri et al. (2021) in other studies. The following values were assumed:

- Diameter of the inclined ribs: 0.250, 0.375 and 0.500 mm;
- Diameter of the horizontal ribs: 0.250, 0.375 and 0.500 mm;
- Thickness of the skins: 1.0, 1.5 and 2.0 mm.

3. Results and discussion

The maximum von Mises stresses obtained in the inclined ribs, horizontal ribs and skins are reported in Table 1 for the nine finite element simulations conducted according to L9(3^4) Taguchi array. Von Mises stress distributions in the elementary cell for Cases 1, 5 and 9 are shown in Fig. 2 as examples.

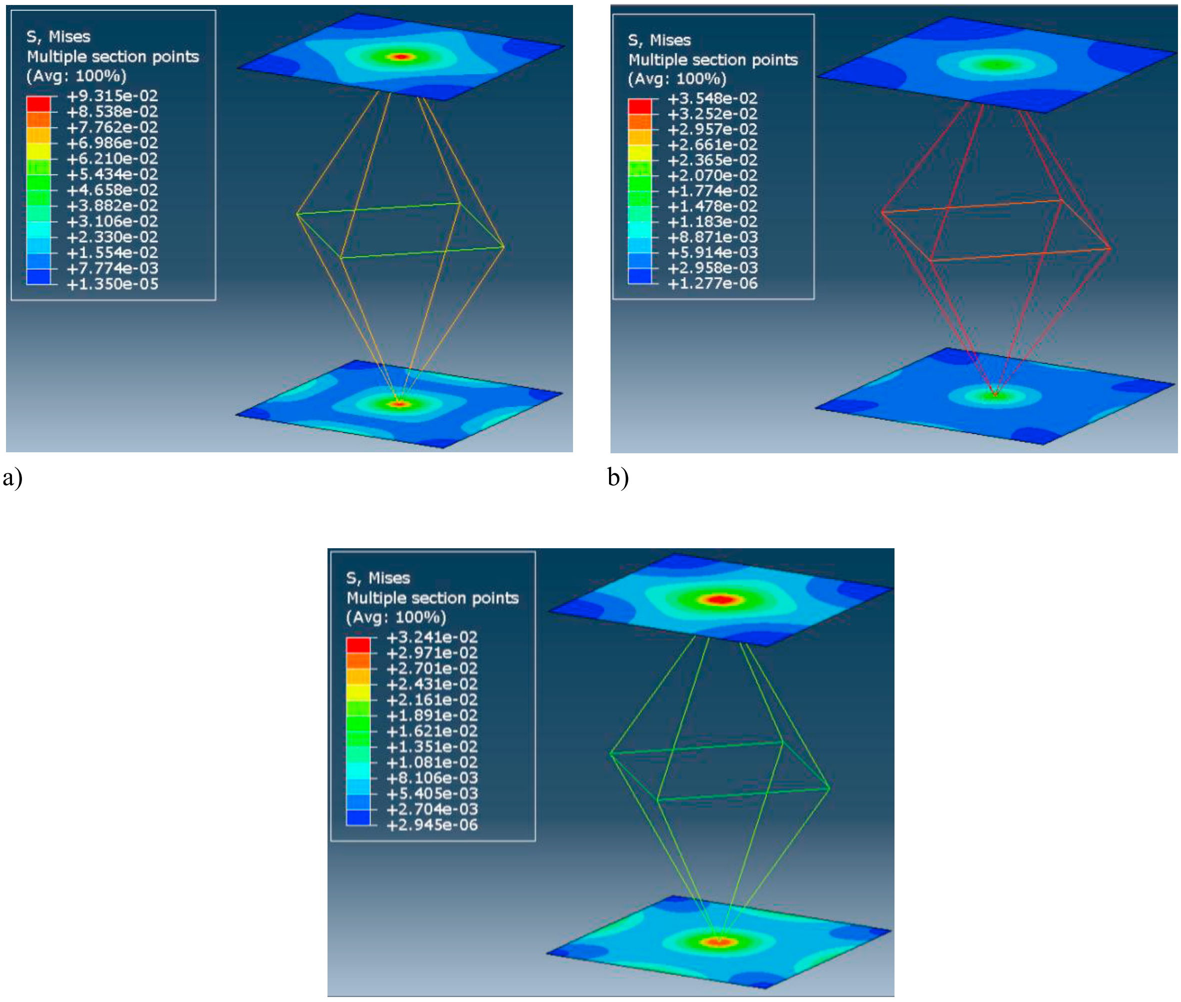
Table 1. Maximum von Mises stress for the nine finite element simulations.

Case	Inclined ribs – Diameter (mm)	Horizontal ribs – Diameter (mm)	Skin – thickness (mm)	Inclined ribs – Stress (MPa)	Horizontal ribs – Stress (MPa)	Skin – Stress (MPa)
1	0.250	0.250	1.0	76.44	59.86	93.15
2	0.250	0.375	1.5	78.16	28.51	41.78
3	0.250	0.500	2.0	80.23	17.27	23.57
4	0.375	0.250	1.5	34.52	62.93	36.34
5	0.375	0.375	2.0	35.48	30.28	20.54
6	0.375	0.500	1.0	33.90	14.86	80.67
7	0.500	0.250	2.0	19.56	64.42	18.52
8	0.500	0.375	1.0	18.95	25.89	71.95
9	0.500	0.500	1.5	19.39	15.66	32.41

The maximum von Mises stress obtained in the inclined ribs ranges from 18.95 MPa (Case 8) to 80.23 MPa (Case 3). The smallest diameter (0.250 mm), which was tested in Cases 1–3, consistently results in the highest stress levels obtained, due to the smallest stiffness of the ribs. As the diameter increases to 0.375 mm (Cases 4–6) and 0.500 mm (Cases 7–9), the stress in the inclined ribs decreases significantly.

Stresses in the horizontal ribs vary from a minimum of 14.86 MPa (Case 6) to a maximum of 64.42 MPa (Case 7). The highest stresses are observed in Cases 1, 4 and 7, which correspond to configurations with the smallest horizontal rib diameters (0.250 mm). Increasing the diameter to 0.375 mm (Cases 2, 5, 8) and to 0.500 mm (Cases 3, 6, 9) leads to a marked stress reduction, highlighting the influence of cross-sectional geometry on load bearing capacity of the horizontal ribs.

The maximum stress value in the skins varies in a wide range, from 18.52 MPa (Case 7) to 93.15 MPa (Case 1). The highest stress occurs in Case 1, which corresponds to a configuration with thin skin (1.0 mm) and slender ribs (0.250 mm), indicating a limited load-bearing capacity of the elementary cell. In contrast, the lowest stresses in the skins occur in Cases 5 and 7, which both present a skin thickness of 2.0 mm, confirming that increasing the skin thickness effectively reduces stress levels. The stress distribution in the skin is also influenced by the diameter of the inclined ribs, even if partially. For instance, with a skin thickness of 1.0 mm, stress values decreased as inclined rib diameter increased, as shown by the Cases 1, 6 and 8.



a) b) c)

Fig. 2. Von Mises stresses (GPa): (a) Case 1; (b) Case 5; (c) Case 9.

The location of the maximum von Mises stress varies across the tested cases. The highest stress levels occur in the inclined ribs for Cases 2, 3 and 5, in the horizontal ribs for Cases 4 and 7 and in the skins for Cases 1, 6, 8 and 9, depending on the combination of the geometric parameters. These results highlight that both skin thickness and rib geometry influence the overall stress state and the location of the maximum stress in the elementary cell. For this reason, an optimal design configuration is necessary to avoid stress concentrations in any single component. The lowest overall stress levels are obtained for Cases 5 and 9, with a maximum stress of 35.48 MPa in the inclined ribs (Case 5) and 32.41 MPa in the skins (Case 9). Case 5 corresponds to a moderate diameter of both inclined and horizontal ribs and thick skins, while Case 9 corresponds to large ribs and moderate skin thickness. These configurations provide a more balanced load distribution and reduced peak stresses.

4. Conclusions

This study presents a finite element analysis of anisogrid sandwich structures with an octahedral core. The aim is to identify the influence of inclined rib diameter, horizontal rib diameter and skin thickness on the stress distribution in an elementary cell under compressive loading. A Taguchi array was used to efficiently explore the design space with a reduced number of simulations. The obtained results highlight the following conclusions:

- Increasing the diameter of the inclined ribs significantly reduces the stress experienced by them, due to a corresponding increased stiffness.
- Similar to the inclined ribs, increasing the diameter of the horizontal ribs leads to lower stresses.
- Skin thickness plays a critical role in reducing the maximum von Mises stress. Configurations with thicker skins show substantially lower stress values compared to those with thinner skins. However, rib geometry also influences the stress state in the skins. Notably, thinner skins combined with slender ribs result in stress concentrations, while increasing rib diameter helps mitigate this effect.
- The location of maximum stress varies among components depending on geometry, pointing out the need for a balanced design.
- Grid geometries with moderate rib diameters and thick skins or with large ribs and moderate skin thickness provide more uniform stress distributions and lower peak values.

These results provide a foundation for more comprehensive design optimization studies, which can potentially include dynamic loading conditions. The present work has not investigated the buckling behavior of the ribs, which could be the subject of future investigations.

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