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Research Article

Modeling and Analysis of Anisogrid Lattice Structures Using an Integrated Algorithmic Modelling Framework

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Keywords

Algorithmic Modelling, Anisogrid Lattice Structures, Composite, Composite Structures, Grid Shell.

Abstract

Lightweight structures have become very important in many technological applications such as aerospace, automotive, shipbuilding, and defense industries. This paper studies the composite lattice structures (Anisogrid Lattice Structures) as one of the main solutions. The term Anisogrid lattice Structure is predicated to Anisotropic Grid Structures. In this study, Anisogrid lattice structures are modeled using a 3D algorithmic modeling technique. 3D models are transferred into the finite element analysis environment integrated into the algorithmic modeling environment and then the finite element analysis is carried out on it. The results obtained from finite element analysis are compared with those obtained from experimental tests. The results of the numerical analysis obtained from this study show that the acceptable conformance with the results of experimental tests was carried out in past literature. The results show that algorithmic modeling can be used as a flexible modeling method for modeling of Anisogrid lattice structures.

1. Introduction

According to triangular trusses efficiency, in 1964, Dr. Robert R. Meyer has begun to find an optimum pattern for stiffening under pressure loads. It has produced immense results and expanded into cylinders as an independent research and development program. The new structure has been called the "Isogrid" because it has behaved like the isotropic material [1]. The isogrid is a name that used to refer to continuous reinforced structures and shells that the grids form an equilateral triangular pattern (Figure 1). This pattern allows the structure to exhibit rigidity to weight and the strength to weight characteristics that are expected in many applications. Also, the repetitive pattern is a major factor in reducing the cost of construction caused by the efficient use of capital equipment and rapid construction methods [2]. Composite materials are widely used in many applications, such as aerospace, defense, automotive, and sports applications, due to their good mechanical, flexibility, and easy manufacturing characteristics. The term Anisogrid Lattice Structure is predicated to Anisotropic Grid Structures according to ref. [3].

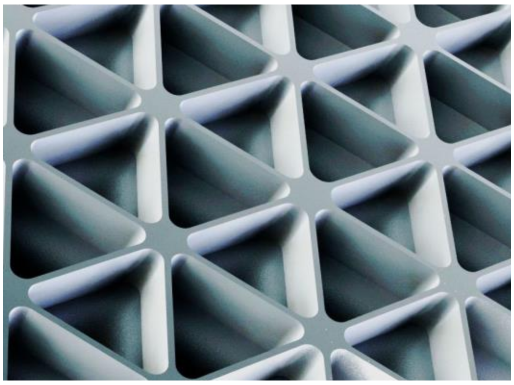

Figure 1. Isogrid Machined Aluminum Panel

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Contrary to the Isogrid structures, the Anisogrid structures can be consistent with different patterns and are not limited to the equilateral triangle. In other words, they can be nonisotropic in terms of both material and structural patterns. Anisogrid structures can make with skin or not depends on the design requirements. Advanced anisogrid lattice structure formula, weight, bending stiffness, and suggested fabrication procedure has defined in a NASA technical memorandum in 1975 [4]. An HM-S/X-30 graphite/epoxy composite curved Isogrid panel, maid using the thermal pressure forming method, has introduced in ref. [3] which shows superior material strength and thermal stability properties with minimal tooling complexity. Although advances in Anisogrid structures has started lease than 50 years ago [5], one of ancient evidence of using of such structures can be seen in Turkmens traditional homes called Yurt (Figure 2).

Figure 2. Turkmens traditional homes (Yurt)

They have been using a wooden lattice structure as the core of their homes for a long time ago. The structure comprises an angled assembly or latticework of pieces of wood or bamboo for walls, a door frame, ribs (poles, rafters), and a wheel (crown, compression ring) possibly steam-bent [6].

Several studies have been carried out on the analysis and optimization of anisogrid lattice structures. Thomas D. Kim (1999) has explained the test and manufacturing of composite isogrid rigid cylinders. The axial compression test objective has identified various fault patterns in structures, such as ribs, skin collapse, and general instability. Rib failure has been found as a critical failure mode for anisogrid cylinder [7]. Samuel Kidanea et al. study has generally determined the overall buckling load for the cross and horizontal grid-hardened composite cylinder. In this assay, the matrices associated with stiffeners have identified by coupling and bending matrices (respectively, based on A, B, and D). Using the energy method, the buckling load has solved for a specific stiffener configuration. The buckling test has also performed on the hardened composite cylinder and has compared with the analytical results [8]. G. Totaro and Z. Gurdal has proposed an optimization method for the composite lattice shell structures under axial compressive loads, aimed at preliminary design. The proposed method has allowed the designer to implement numerical minimization to easily process the optimal configurations located at least near the Mass solution [9]. Morozov et al. have examined the buckling behavior of cylindrical shells of the anisogrid composite cage under axial pressure, transverse bending, pure bending, and torsion. Three-dimensional frame structures have modeled in lattice shells, consisting of curvilinear ribs subjected to stretching/clamping, in two planes and torsion bending. The length-changing effect of the shells, the number of helical beams, and the orientation angles on the buckling behavior of the cage structures have analyzed using parameter analysis. Cage crusts with cuts have also analyzed for buckling [10]. In a study has established by M. Buragohain and R. Velmurugan three different non-rigidized shells of circular cylindrical structures, cage cylinder (rib only) and grid hardened shell (with shell and ribs) have evaluated for experimental study and adapted to a series of structures simplified and cheaper production process they had. Axial pressure tests have performed and the results compared with finite element analysis [11]. Tom Mathew and colleagues have investigated the strength of composite grid lattice structures and tried to obtain the most heavily efficient design with the highest compressive load efficiency. Besides, the structure has analyzed using MSC Patran finite element software and parametric studies. The cylindrical gridded model and different loading conditions have evaluated with the conical graded model. It has been found that the ratio in width is possible to withstand a load of 400kN up to 2.5 and 30º helix angle structures. It has been providing a very high weight-strength ratio and cost advantages [12].

In general, anisogrid structures are produced by the continuous automatic filament winding method. Anisogrid structure is making with fiber-reinforced composite and thin ribs, so they are light weighted and have high resistance to loads. According to the literature, 3D shell or beam elements can be proposed as the different analysis elements. The analysis may be performed by various commercial programs such as ABAQUS, ANSYS, and SAP.

Anisogrid lattice structures Finite Element modeling is a time-consuming procedure and requires the development of a special program. Today, by the development of parametric modeling software, this problem has been solved relatively. The flexibility of these programs is not as large as algorithmic modeling programs. In this paper, an environment for the algorithmic modeling of anisogrid structures is designed. More precisely, the structure in this environment, instead of being modeled, is programmed. This is very important when we need to make extensive changes in the various parameters of finite element models to complete an optimization procedure.

2. Algorithmic Modeling

Anisogrid (anisotropic grid) composite lattice structures are usually made in the form of a cylindrical or conical shell consisting of helical and circumferential (hoop) unidirectional composite ribs formed by continuous winding (Figure 3).

Figure 3. Typical Anisogrid Lattice Cylindrical Shell

Anisogrid carbon-epoxy lattice structures are normally designed for axial compression as the main loading case. The ribs are the principal load-bearing elements of the structure, whereas the skin, the presence of which can be justified by design requirements, is not considered as a load-bearing element in the design of lattice structures [13]. The Grasshopper is a platform in Rhino to deal with the Algorithmic modeling. Rhinoceros (Rhino) 3D is a CAD / CAM design software used in 3D modeling and prototyping, especially in industrial applications. It is more suitable for obtaining 3D prototypes as it uses NURBS modeling instead of mesh modeling. Grasshopper is an add-on program that allows algorithmic modeling using Rhino History. In 3D Grasshopper, geometry of anisogrid structures are models using a developed algorithmic modeling framework. The algorithmic modeling framework consists of various command blocks connected through data wires. The variables of each command are defined in the command blocks in the form of inputs and outputs. Figure 4 shows an overview of the modeling framework.

ANSYS finite element software is used for FEM analysis. Anisogrid structures made by continuous fibers consist of slender ribs with a small cross-section. It is appropriate to use the beam element in the analysis. 3D beam 188 elements are selected for FEM analysis which is supporting orthotropic materials. It also is 3D and has 6 degrees of freedom and is based on the Tymoshenko beam theory. The framework constitutes a text file compatible with the ANSYS APDL program in four steps. In the first step; The shape of the pattern is formed in the plane (Figure 5).

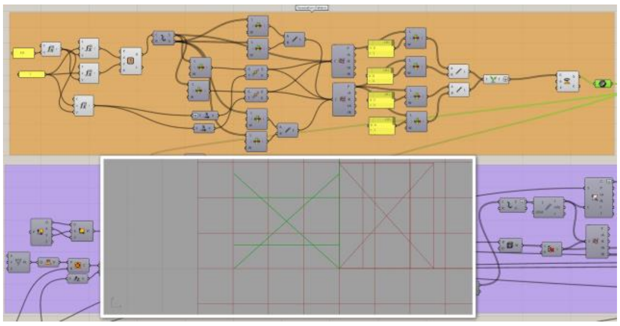

Figure 5. Lattice Pattern Modeling Block

In the second step; the determined pattern is projected onto the cylindrical shell and at the same time divided into elements according to the FEM analysis program (Figure 6).

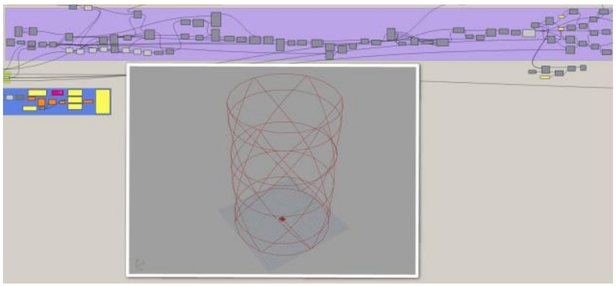

Figure 6. Cylindrical Shell Mapping Block

In the third step; The model is placed into a suitable shape for analysis and also material properties, cross-sectional area, shape, loads, and boundary conditions are applied. Figures 7,8 show FEM modeling block and 3D geometries respectively. In the fifth step; The model is recorded as an ANSYS APDL file. This file carries the analysis model to the ANSYS finite element analysis program automatically. The ANSYS program starts analyzing after reading the APDL file. In this analysis, the critical buckling loads of each model are determined according to the first mode. Figures 9,10 and 11 show the finite element model and the displacements respectively. The upper flange of the cylindrical structure has a distributed unit load and the lower part is completely fixed.

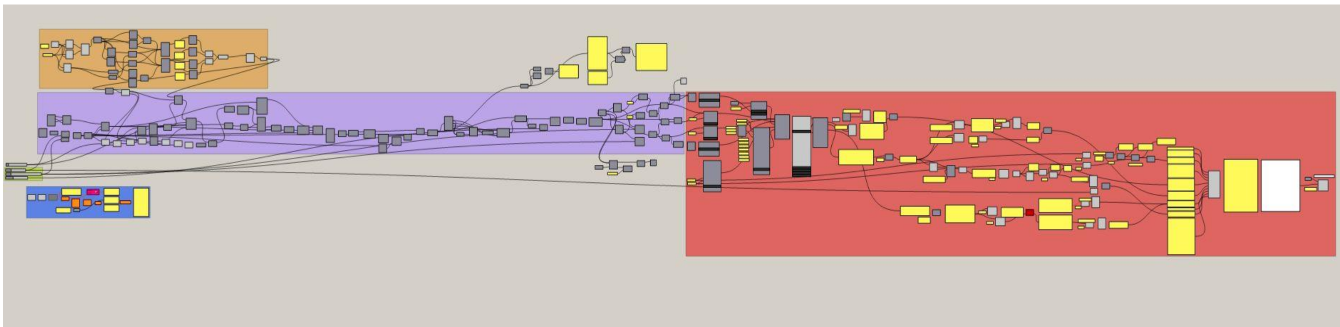

Figure 4. Overview of Algorithmic Modelling Framework

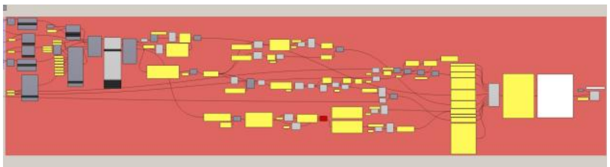

Figure 7. FEM model constructing block

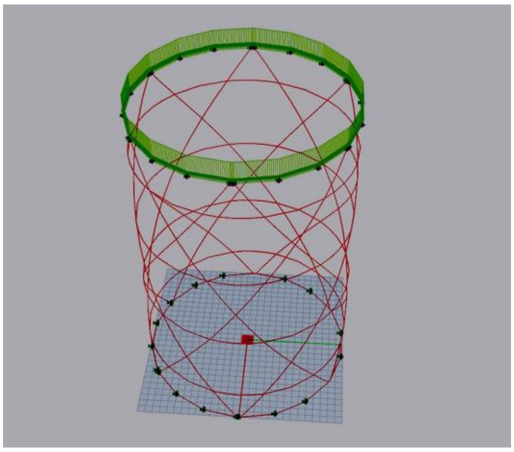

Figure 8. Typical 3D geometry model

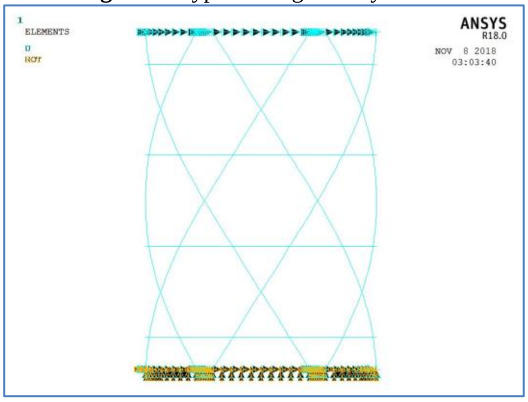

Figure 9. Exported 3D Wireframe model in ANSYS

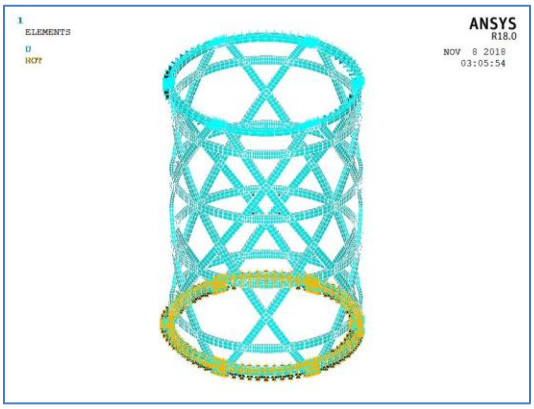

Figure 10. 3D real size model in ANSYS

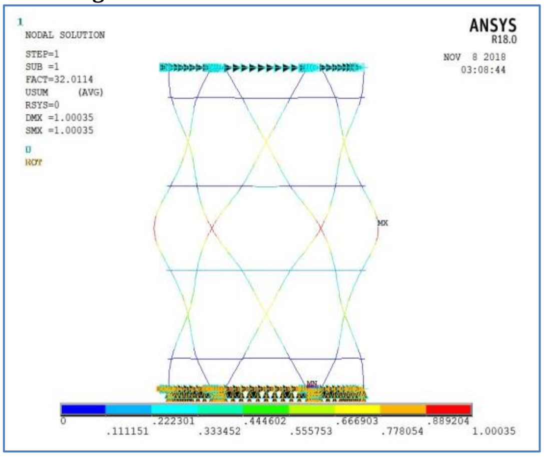

Figure 11. Displacement plot in ANSYS

3. Analysis and Results

To evident the correct operation of the program, modeling and analysis were done by taking a few samples from the literature. Table 1 provides some results from Buragohain et al. [11] and their comparison with the results of this paper.

There is a 5.6% difference between the results according to the numerical FEM analysis. The reason for this is that the models formed by a different method in this study. Due to the use of curved lines instead of linear ones in the models used in this study, it is considered that more realistic results are obtained than studies in the literature [14].

Table 1. Analysis result of sample Anisogrid Lattice Structure

Model Dimensions (mm)		Material Properties		Buckling Load (KN)			Differences (FEM Analysis) %
				Literature		This Paper	
Diameter	140	Carbon fiber(T300), Epoxy (LY55/HY5200)		FEM	Experimental	FEM	
Height	204	E_{11}	44.2 GPa				
Ribs Dimensions	3.2×6	E_{22}	5.0 GPa	30.2	33.4	28.5	5.6
	4.0×6	G_{12}	2.4 GPa	50.9	58.1	48.2	5.3
	4.8×6	ν_{12}	0.194	78.6	78.8	74.3	5.5

4. Conclusion

An algorithmic modeling environment has developed for modeling anisogrid structures. A Model has created in the algorithmic framework and transferred to the ANSYS FEM analysis program, finally buckling analysis is carried out. To verify the accuracy of the results, these results have compared with experimental and numerical studies. The results are consistent with the results of previous studies. The maximum difference between the results of this analysis and previous studies is 5.6%, which seems to be due to the difference in the modeling and analysis environment. Regarding the results, it can be said that the algorithmic modeling environment is a flexible and suitable environment for anisotropic structure modeling, especially when there is a need for continuous changes in design parameters and frequent analysis.

Acknowledgements

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Conflict of Interest Statement

The authors declare no conflict of interest.

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