Finite Element Analysis of Varying Thickness Carbon Composite Isogrid Structures: A Study on Strength, Stiffness, And Weight Efficiency

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Abstract*- Isogrid structures have long been admired for their remarkable structural efficiency and weight-saving characteristics, making them a preferred choice in various engineering applications. This research paper presents a comparative study to determine the optimal isogrid design for a given loading conditions lightweight structural applications. Three distinct carbon composite isogrid configurations are selected and analyzed using commercially available Finite Element (FE) software (ABAQUS), and a comparison of stiffness and strength has been made.*

Keywords- Isogrid Structures, Carbon Composite Material, Finite Element Analysis,Abaqus.

I. INTRODUCTION

The Isogrid structures are classified as three-dimensional lattice structures. It has several advantages, they are lightweight, they have high strength, high stability, great energy absorption, superior damage tolerance, and low manufacturing cost[1-4]. In aerospace engineering grid stiffness composite panels have been used for payload fairings for launch vehicles and for load bearing structure for satellites. Many researcher of last decades have devoted themselves to studying grid stiffness composite panels [5-9].

They are not only competitive with conventional stiffened constructions and sandwich shells in terms of weight but also enjoy superior damage tolerance properties.

In present paper a comparative study of strength and stiffness has been made between three different isogrid structures. Overall dimesnsions of the grid is constant, but thickness of skin and grid has been changed.

GEOMTRY AND MATERIAL PROPERTIES

An isogrid structure as shown in the figure is considered for structural analysis. The overall dimension is of 500mm × 500mm, where as grid size is 112mm × 90mm

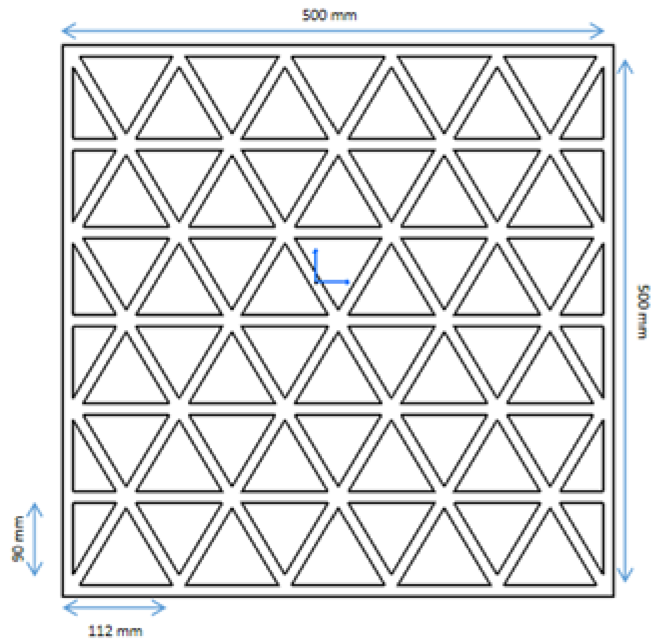

Figure 1: A square isogrid 500mm × 500mm

The table below provides an explanation of the material properties for the carbon composite material utilized.

Table below shows the material properties of the carbon fibers used in analysis

S11(+)	535 MPa
S11(-)	418 MPa
S22(+)	20 MPa
S22(-)	51 MPa
S12	36 MPa

Table below shows the strength parameters of the carbon fibers used in the analysis.

Elastic (lamina)	
Elastic modulus in fiber direction E_{11}	112 GPa
Elastic modulus in transverse direction E_{22}	8.9 GPa
In plane shear modulus G_{23}	6.7 GPa
Poisson's ratio υ_{12}	0.275
Density	1500 kg/m^3

Three different isogrid as shown in the table considered for comparative study. Isogrid 1 has a skin of 2.88mm thickness and grid of 2.88mm thickness. Whereas isogrid 2 has a skin of 2.88mm thickness and grid of 5.76mm thickness. Isogrid 3 has a skin of 5.76mm thickness and grid of 5.76mm of thickness.

NOMENCLATURE	SKIN THICKNESS	GRID THICKNESS
S2P88G5P76	2.88 mm	5.76 mm
S5P76G2P88	5.76 mm	2.88 mm
S5P76G5P76	5.76 mm	5.76 mm

Table below shows the layup sequence or ply orientation for isogrid 1. skin has 16 layer or plies and grid contained 32 layers or plies, having each ply a thickness of 0.18mm.

Components	Ply sequence
Skin (2.88mm)	$[45/0/-45/90/45/0/-45/90]_s$
Grid (5.76mm)	$[(45/0/-45/90)_4]_s$

Table below shows the layup sequence of or ply orientation for isogrid 2. where skin contained 32 layers or plies and grid contained 16 layers or plies.

Components	Ply sequence
Skin (5.76mm)	$[(45/0/-45/90)_4]_s$
Grid (2.88mm)	$[45/0/-45/90/45/0/-45/90]_s$

Table below shows the layup sequence or ply orientation for isogrid 3. skin and grid both contained 32 layers or plies, having each ply of thickness 0.18mm

Components	Ply sequence
Skin (5.76mm)	$[(45/0/-45/90)_4]_s$
Grid (5.76mm)	$[(45/0/-45/90)_4]_s$

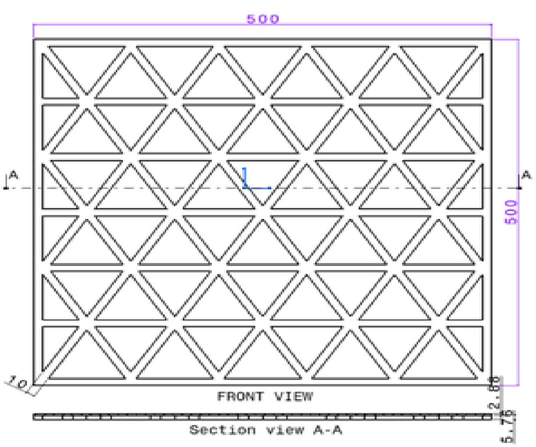

Figure 2: isogrid 1 (skin thickness 2.88mm and grid thickness 5.76mm)

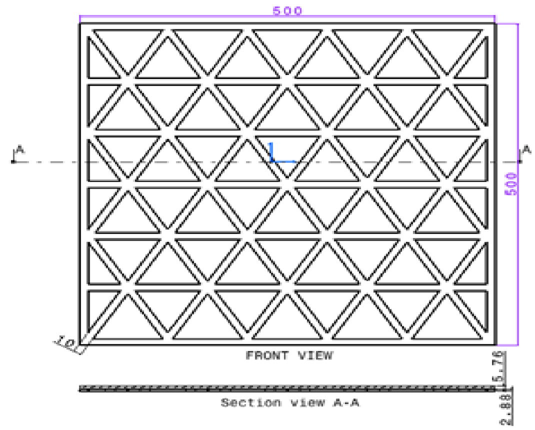

Figure 3: isogrid 1 (skin thickness 5.76mm and grid thickness 2.88mm)

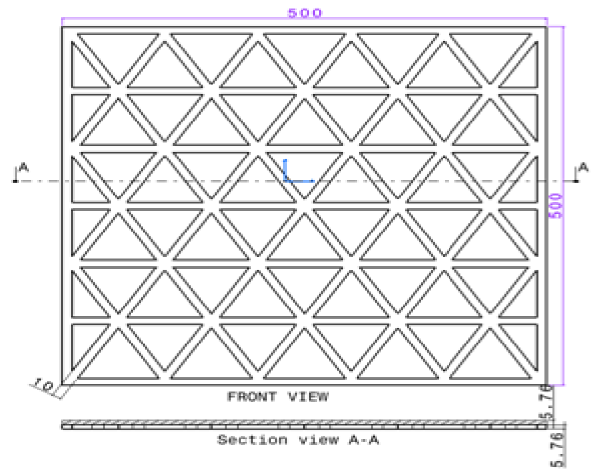

Figure 4: isogrid 1 (skin thickness 5.76mm and grid thickness 5.76mm)

II. RESULT

As discussed in the methodology we have done static structural analysis in the assembly in three different assembly with varying thickness and the results are shown below.

Firstly we have shown tsai-hill stress criteria on all three accounts of thickness varied assembly and result are shown below

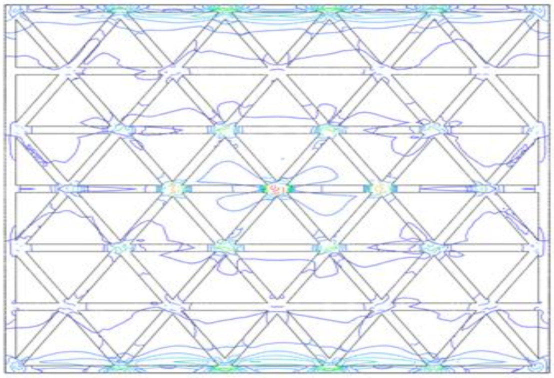

Figure 5: isosurface contour for isogrid S2P88G5P76

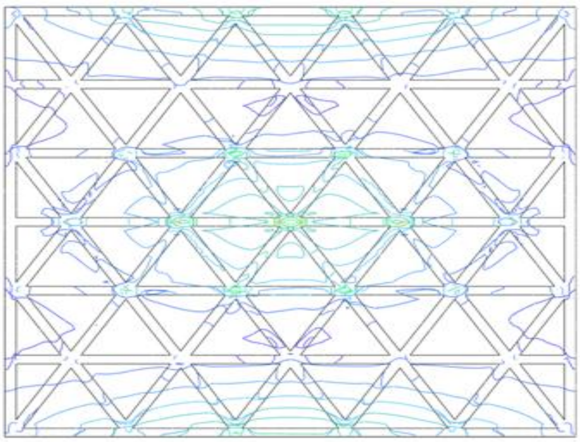

FIGURE 6: isosurface contour for isogrid S5P76G2P88

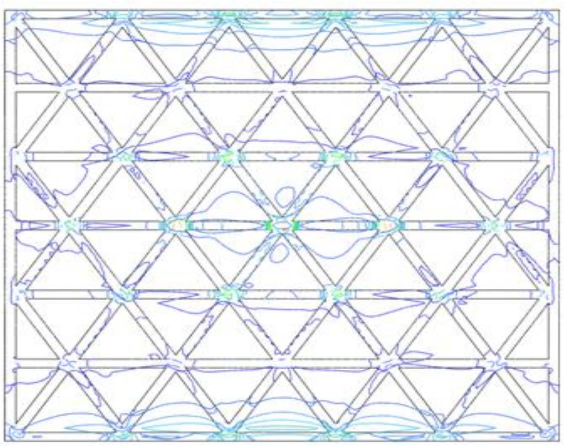

Figure 7: isosurface contour for isogrid S5P76G5P76

Below table shows comparision between isogrid of different thickness made of carbon T700s and steel Showing difference in reduction percentage of weight and stresses generated between them.

Table no. 1

	weight	stress
S2P88G5P76	76.6141332	11.56409046
S5P76G2P88	76.89552239	69.40732057
S5P76G5P76	76.77419355	11.2544282
8.64mm(plate)	77.64705882	-25.3473156
11.52mm(plate)	77.0619469	-17.1858816

The isogrid design with S5P76G2P88 shows a 69.4% reduction in stress compared to other configurations.The deformation value for the same has a significant reduction of 47.84% from steel material of same configuration.

This confirms that isogrid design with 2/3rd skin and 1/3rd with isogrid configuration is the optimal design for isogrid design structures

Like metals composite also have different failure criteria I.e. maximum stress theory, maximum strain theory, tsai-hill theory tsai-wu theory

III. DISCUSSION

Starting with the displacement, we can see that displacement for 2 grids with constant thickness here is exactly same, which is due to smaller size of the grid.(this changes in very little as we increase the size of the grid). Our purpose here is to only study difference between varying thickness and constant thickness.

The Isogrid design has consistently demonstrated its remarkable ability to mitigate stress concentration by offering an enhanced and more even distribution of stress across the surface, thus significantly enhancing the structural integrity and performance. However, our comprehensive study, conducted with meticulous scrutiny and precision, has unveiled intriguing insights into the design's adaptability and effectiveness across a spectrum of sizes and shapes. Intriguingly, it becomes evident that not all Isogrid designs are created equal, as each exhibits unique characteristics and performance attributes. Notably, the Isogrid configuration boasting a 2:1 ratio of grid to skin thickness emerges as a standout choice, showcasing superior stress dispersion capabilities. This particular design option has the distinct advantage of effectively facilitating stress flow across the surface, which renders it an attractive choice, not only for applications where stress distribution is paramount but also for larger platforms where stability and load-bearing capacity are pivotal considerations.

In the displacement vs time graph we can see that constant thickness lines represent that they have higher displacement values compared to the varying thickness. This shows constant thickness will give higher deformation when impact is done on it.

While reviewing the tsai-hill stress result we can see, constant thickness isogrid has lower stress and stress is distributed over the area. This can be helpful in designing larger platform areas. Varying thickness isogrid design can resist more impact and can be used for smaller surface area.

Conversely, when dealing with shorter platforms, plates, or areas where size constraints are more pronounced, a different approach emerges. The utilization of sheets or plates of constant thickness takes precedence due to their inherent ability to absorb and distribute stress more effectively over shorter surface areas. This strategic choice is especially suited for scenarios where the probability of high-impact events is significantly heightened. Expanding on this multifaceted design landscape, we delve into the realm of materials. Incorporating carbon composite materials into the Isogrid design paradigm serves as a potent trifecta of innovation. First and foremost, it offers a profound advantage in weight reduction, enhancing the overall efficiency and functionality of the structure or body. The reduced weight not only optimizes performance but also contributes to enhanced fuel efficiency, thereby marking a milestone in sustainable design practices. The integration of carbon composite materials in an Isogrid framework enhances structural rigidity, mitigating deformation issues that may arise under stress, subsequently diminishing the generation of bending stress across the surface. This proactive approach stands as a testament to our commitment to longevity and resilience in design.

IV. CONCLUSION

As we can see varying thickness gives us two different result to discuss

1. Assembly with varying thickness have lower stress values but relatively more displacement
2. Assembly with constant thickness for grid and skin have higher stress values but lower displacement

This result can help us in deciding the use of the isogrid design in the different region and weight application.

A. varying thickness in isogrid design can be used for smaller area will have comparatively more displacement and lower stress over whole body that will help in resisting the impact on the body significantly.

B. constant thickness in isogrid design can be used in larger area platforms were surface area of the element is larger. So the larger area will have to have less displacement and stress will be distributed over the area in constant thickness design.

The utilization of carbon composite materials within the Isogrid configuration significantly elevates the quality and durability of composite-manufactured body parts. It acts as a formidable defense against issues such as delamination, reducing the vulnerability of these components to structural compromise. The composite manufacturing process benefits from the inherent advantages of carbon composite materials, which not only improve overall performance but also streamline production and assembly processes.

If we conclude work as a application for real world ,

Aerospace : Isogird design with varying thickness can be used for nose design and and constant thickness design can be used for fuselage design for aeroplane

Vehicle : constant thickness design can be used for door and roof. With varying thickness design of skin and isogrid.

Construction : varying thickness design can be used for building larger platforms which can be used in bridges

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