

# Static energy absorption capacity of grid stiffened composite plates

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## Abstract

This paper presents an experimental study on the energy absorption capacity of iso-grid and ortho-grid stiffened composite plates under transverse loading. The 3-point bend test has been performed to investigate the energy absorption behavior of grid stiffened composite plates. The test results show that energy absorption capacity up to failure is improved when the load is applied on the rib side. The ortho grid stiffened structure shows a higher energy absorption capacity after failure when loaded at the rib side. The main failure modes in grid stiffened composite plates are rib fracture, matrix cracking and delamination over the skin.

*Keywords:* energy absorption, ortho-grid, iso-grid, stiffened plate, delamination, matrix cracking.

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## 1. Introduction

Applications of fiber-reinforced plastic (FRP) composites are fast gaining popularity in many engineering disciplines. Amongst many of such applications, plate/ panel /shell type of structural elements act as the main load-bearing components. The addition of stiffener in such structures improves the overall efficiency of the structure. Grid stiffened structures are those structures having interconnected grid-like arrangement. The interconnected grids are called stiffeners. It has been found that due to the addition of stiffeners grid stiffened structures have high strength, high stiffness to weight ratio, good impact and fatigue resistance, good damage tolerances. Due to their improved properties grid stiffened structures are widely used in the aerospace industry, automotive parts, missile, marine industries, and many others.

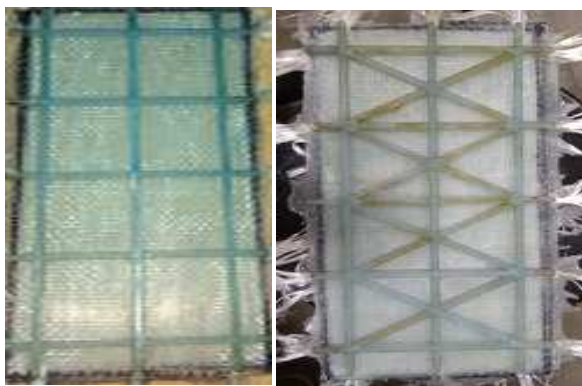
The grid structures can be many types, Bi-grid, Tri-grid, and Quadric-grid. Further, they can also be classified as iso-grid and ortho-grid. This paper mainly focuses on the fabrication and experimentation of iso-grid and ortho-grid stiffened composite plates under a 3-point bend test. Fabrication is done using the Hand lay-up technique. The main aim of this study is to evaluate the basic failure behavior and calculation of energy absorption of iso-grid and ortho-grid stiffened plates under the 3-point bend test. Obtained results may be useful for the design of applications like launching pads and floor grating, weight critical automotive side-impact and crashworthy applications, where failure due to impact is the main concern and describe the importance (significance) of the work - why was this worth doing in the first place? Provide a broad context.

## 2. Specimen fabrication

To understand the energy absorption capacity and damage evolution of iso-grid and ortho-grid stiffened composite plate 4 specimens are made for each category. Stacking sequence  $[0/90]_s$  degree with 4 layers of skin has been used. Specimen dimension are  $300 \times 130 \text{ mm}^2$  according to standard ASTM D7264. Glass fiber fabric, Epoxy LY556 (IUPAC name, 2-(Chloromethyl) oxirane; 4-[2-(4-hydroxyphenyl) propane- 2-yl phenol] has been used as resin matrix material. Hardener (Aradur HY 951) has been mixed in the epoxy in the ratio of 1:10 by volume. The relevant properties are given in Table 1 and Table 2.

**Table 1.** Glass fiber fabric

Property	Specification	SI unit
Weave	Plain	-
Areal weight	600	GSM
Dry fabric thickness	0.2	Mm
Density	2.62	$\text{g/cm}^3$
Tensile strength	2.62	MPa
Young's modulus	80	GPa



(a)

(b)

**Figure 1.** Fabricated Specimen (a) Ortho-grid (b) Iso-grid



(a)

(b)

**Figure 2.** Simply supported conditions (a) Load applied skin side (b) Load applied rib side

**Table 2.** Epoxy/ Resin material

Parameter	Specification	SI unit
Aspect (Visual)	Clear, pale yellow liquid	-
Epoxy Content	5.30-5.45	eq/kg
Viscosity at 25°C	10,000-12,000	MPa-s
Density at 25°C	1.15-1.20	$\text{g/cm}^3$
Flashpoint	>200	°C

To fabricate the ribs onto the skin a steel mold has been used 10 mm thickness steel plate has been taken and the slot has been created over the plate using end milling operations. The slot dimensions are  $6 \times 6 \text{ mm}^2$ . Hand Lay-up technique has been used and ribs are fabricated one by one onto the mold. Ribs have been created from the glass fiber fabric. The volume fractions of fibers inside the slots have been taken 50%. The specimen has been left to cure for 48 hours. Specimen has been cut to get desired dimensions. The fabricated ortho-grid and iso-grid specimens are shown in Figure 1(a) and Figure 1(b).

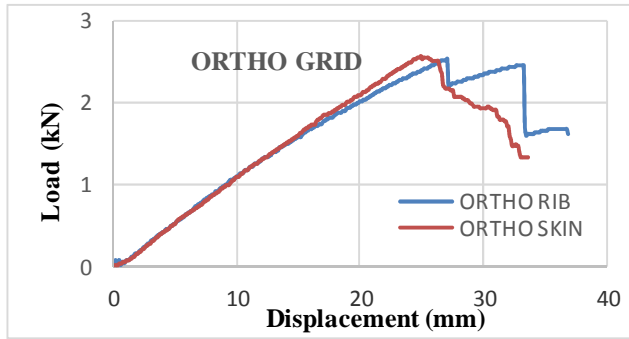
## 3. Test Procedure

Continue To know the behavior of the grid stiffened composite plate under the transverse load 3-point bend test has been performed according to ASTM D7264. In a 3-point bend test, the specimen is simply supported at the sides and load is applied

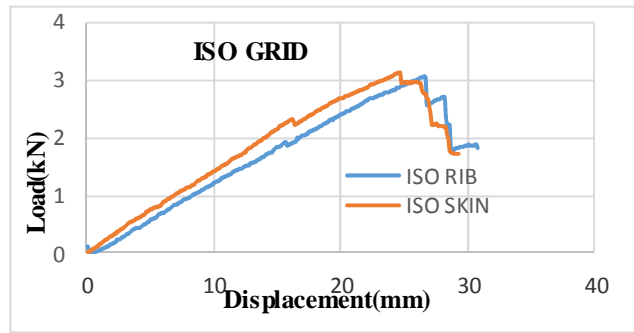
along the centerline of the specimen, in width direction. The standard test speed is 2 mm per minute. The distance between the supports has been maintained as 225 mm. The support conditions of specimens are shown in figure 2(a) and figure 2(b). The force-displacement curve is plotted from the experimental data, as shown in figures 3-6.

The area under the load vs displacement curve is known to be the measure of energy absorption of any structure. The energy absorption ( $E_A$ ) capacity of the grid-stiffened plates in the present case is calculated via the following equation (1).

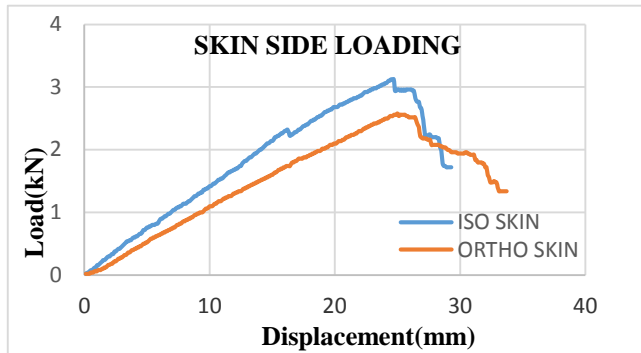
$$E_A = A \tag{1}$$



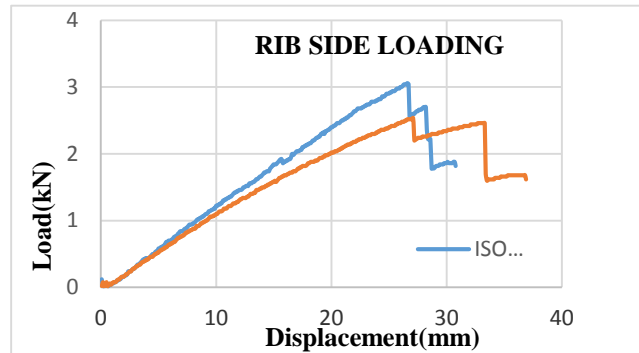
**Figure 3.** Comparison of load vs displacement curve for ortho-grid load applied at rib and skin side.



**Figure 4.** Comparison of load vs displacement curve for iso-grid load applied at the rib side and skin side.



**Figure 5.** Comparison of load vs displacement curve for iso-grid and ortho-grid, load applied at the skin side.



**Figure 6.** Comparison of load vs displacement curve for iso-grid and ortho-grid, load applied at rib side.

where  $A$  is the measure of the area under the load vs displacement curve from the point of failure initiation represented by the peak of the curve up to the maximum displacement of interest.

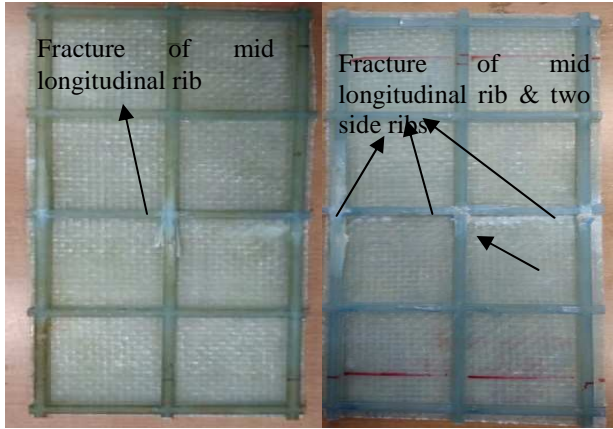
#### 4. Result and comparison

The energy absorption capacity of a grid stiffened composite plate significantly depends on the grid structure and the application of load on the rib side or skin side [4]. The major effects are summarized in this paper.

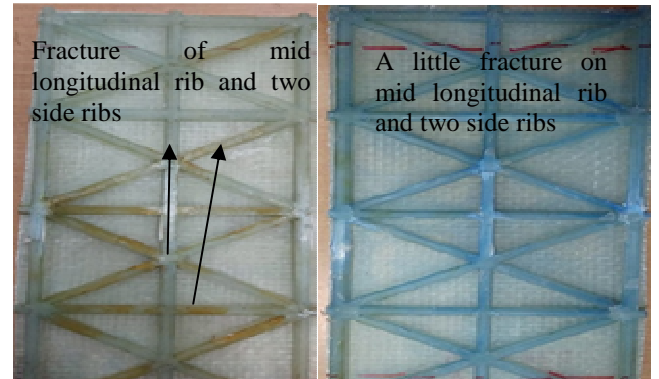
From these described experiments, gradual failure is observed when load is applied at the skin side. A catastrophic failure or a sudden failure is observed when load is applied at the rib side [5]. It indicates specimen behavior in a brittle manner when loaded at the rib side. The comparison of load vs displacement curve for ortho-grid is shown in figure 3 and for iso-grid is shown in figure 4, the load applied at the rib side and skin side. Very little energy is absorbed by the iso-grid as compared to ortho-grid when loaded rib side. Very high displacement ranges are observed in the case of ortho-grid when loaded at the rib side. The energy absorption capacity at failure is significantly improved in the case of iso-grid when loaded at the rib side. Figure 5 shows a comparison of the load vs displacement curve for ortho-grid and iso-grid when load applied at the skin side. Figure 6 shows a comparison of load vs displacement curve for iso-grid when load applied at the rib side.

**5. Failure mode**

In ortho-grid, the failure mainly is due to the fracture of mid-longitudinal rib and matrix cracking over the skin when loaded at the skin side [7]. But when the load is applied at the rib side, fracture of the main longitudinal rib with two side ribs and deboning between the rib and the skin has been observed. In the case of rib side loading distribution of load is observed within the ribs [6]. The same failure patterns are observed in the case of iso-grid. Figures 7 and 8 show the failure modes of the ortho grid and iso-grid (a) loaded skin side (b) loaded rib side.



**Figure 7.** Failure modes of ortho-grid (a) loaded skin side (b) loaded rib side.



**Figure 8.** Failure modes of Iso-grid (a) loaded skin side (b) loaded rib side

**Table 3.** Summarized energy absorption characteristics of ortho-grid and iso-grid stiffened composite plate.

Loading side	Skin Sideloadng		Rib side loading	
	<i>Ortho-grid</i>	<i>Iso-grid</i>	<i>Ortho-grid</i>	<i>Iso-grid</i>
Energy absorption at failure (N-m)	32.25	38.22	34.417	40.698
Energy absorption after failure (N-m)	18.1575	20.939	20.16	5.759
Failure Modes	Fracture of mid-longitudinal rib and matrix cracking over skin.	Fracture of mid-longitudinal rib and two side ribs, matrix cracking at the skin.	Fracture of mid-longitudinal rib and two side ribs, skin cracking, delamination	Little fracture of mid-longitudinal rib and two side ribs, matrix cracking.

**6. Conclusions**

The energy absorption capacity after failure is more for the ortho-grid stiffened composite plate as compared to iso-grid stiffened plate, rib side loading. The energy absorption capacity of iso-grid stiffened composite plate is higher as compared to ortho-grid at failure. The energy absorption capacity at failure of ortho-grid and iso-grid stiffened plate is significantly improved when loaded at the rib side. The main failure mode in the grid stiffened composite plate is rib fracture, matrix cracking, and delamination

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#### **Biographical notes**

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