Contents

1. Introduction

The Composites Design Guide is a reference tool for engineers to use when designing components fabricated from composite materials. When the unique fabrication and material characteristics of composites are designed into a component, composites can be the solution to your needs. This guide is not intended to be an exhaustive treatise of composites, but rather a quick reference for applying composite materials to a component.

We are ready and eager to help you with any question you might have about composite materials as they apply to your application. Please do not hesitate to contact us.

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2. Material Comparisons

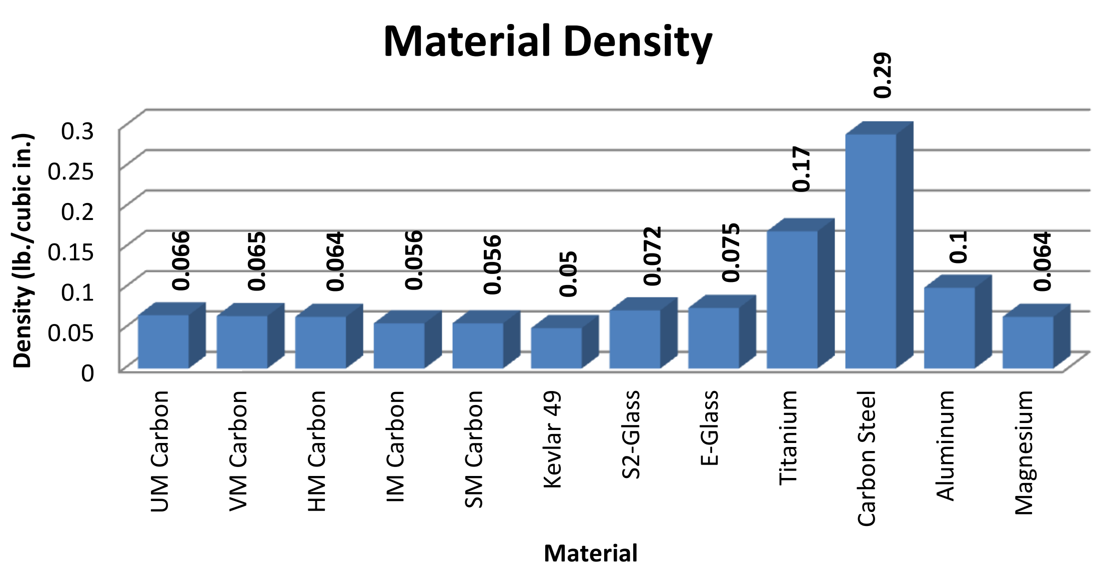
The three dominant fibers used in the composite industry include Fiberglass, Kevlar, and Carbon. Fiberglass is the most widely used followed by carbon and then Kevlar. The performance characteristics are summarized in Table 2.1.

Table 2.1: Fiber Performance Characteristics

Characteristic	**Performance**		
	Carbon	Fiberglass	Aramid (Kevlar)
Cost	Highest	Lowest	
Electrical Resistivity	Poor	Best	
Electrical Conductivity	Best		
Thermal Conductivity	Best	Poor	
Dampening	Good		Best
Compressive Strength			Poor
Machineability	Best	Good	Poor
Toughness			Best
High Temp Strength	Best		Poor
Thermal Expansion	Near Zero	Positive	Negative
Fatigue Resistance	Best		
Impact Strength	Poor		
Environmental Stability	Best	Good	Poor

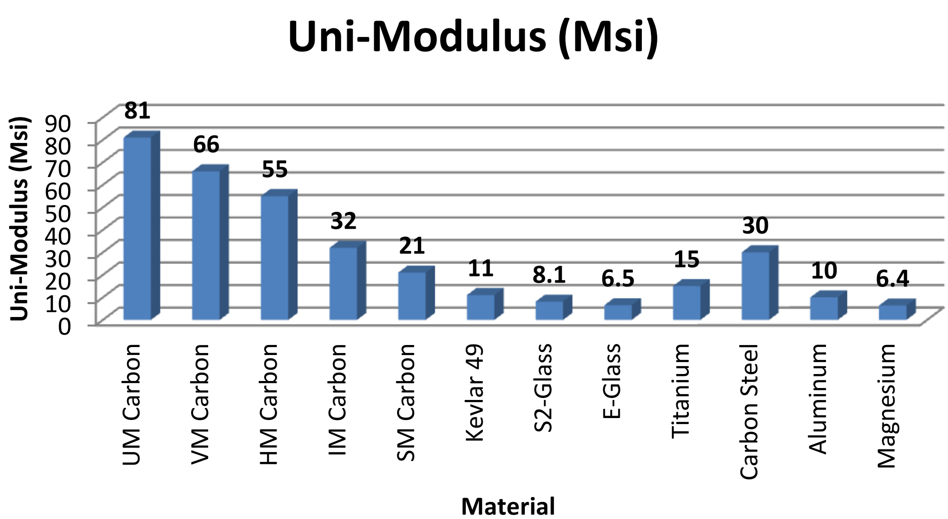
Compared to metallics, composites consistently offer lighter weight materials. Figure 2.1 shows the density comparisons of the composites and metallics. The composite density is based upon a fiber volume of approximately 60%.

Figure 2.1: Density



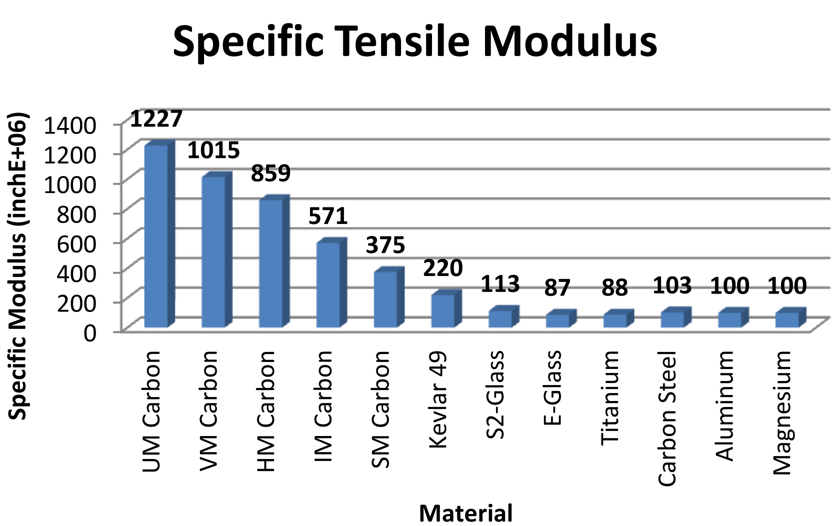
The extensional modulus of composite materials has a diverse range when compared to metallics. Figure 2.2 shows the comparison to metallics. The composite modulus is based upon approximately 60% fiber volume and unidirectional values. *Note: Unidirectional values are the highest possible for a composite material, but may not always be practical due to manufacturing constraints and structural requirements.*

Figure 2.2: Tensile Modulus



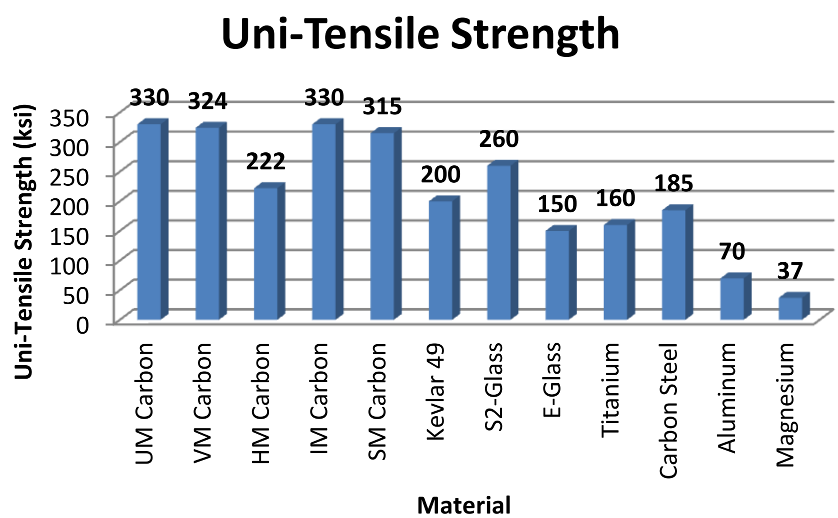
Another way to compare the modulus of composite materials to metallics is to consider the "SPECIFIC MODULUS" of the materials. Specific modulus is calculated by dividing the material modulus by the material density. This parameter gives an indication of the stiffness of the material compared to the material weight. Figure 2.3 shows the Specific Modulus when comparing unidirectional composites at 60% fiber volume to metallics.

Figure 2.3: Specific Tensile Modulus



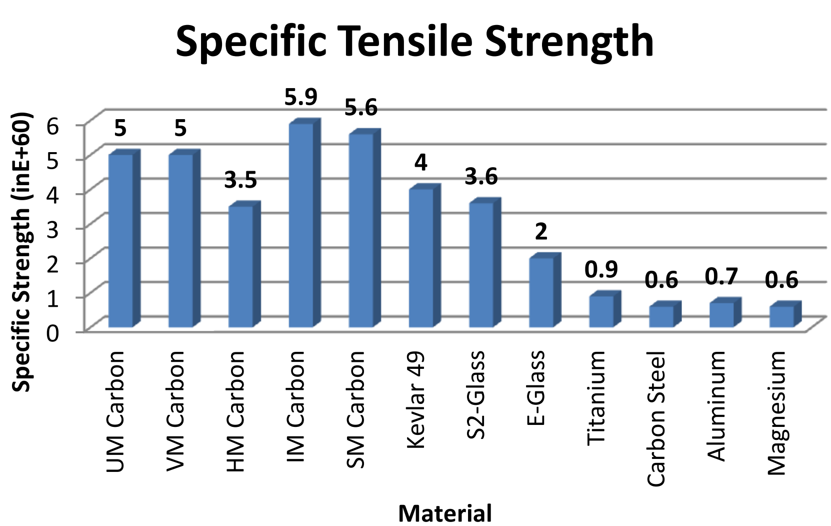
The Tensile Strength of composite materials out-performs that of metallics. Figure 2.4 shows the comparison to metallics. The composite strengths are based upon approximately 60% fiber volume and are unidirectional values. *Note: unidirectional values are the highest possible for a composite material, but may not always be practical due to manufacturing constraints and structural requirements.*

Figure 2.4: Tensile Strength



Like the Specific Modulus, the "SPECIFIC STRENGTH" can be used to compare materials. Specific Strength is calculated by dividing the material strength by the material density. This parameter gives an indication of the strength of the material compared to the material weight. Figure 2.5 shows the Specific Strength when comparing unidirectional composites at 60% fiber volume to metallics.

Figure 2.5: Specific Tensile Strength



3. Fabrication Methods

Three different composite fabrication techniques are used in our company. A general understanding of these methods will aid in identifying how a structure or component may be fabricated, thus defining the geometric and dimensional tolerance factors to consider in a design.

Filament Winding:

Tows or yarns of fiber are wrapped onto a rotating mandrel or core. The fiber may be pre-impregnated with a semi-hardened resin or may be impregnated with a wet resin. The component is then hardened or cured on-mandrel in an oven or autoclave. Figure 3.1 shows the filament winding process and Table 3.1 defines guidelines for selecting the Filament Winding fabrication process.

Figure 3.1: Filament Winding

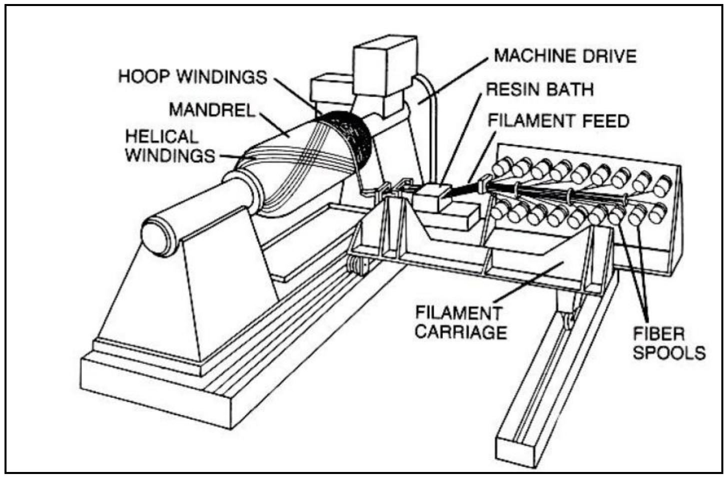


Table 3.1: Filament Winding Selection Guidelines

Item:	Description:
1	Limited primarily to parts with any closed, non-concave, cross-section (i.e. tubes, pipes, vessels)
2	Tapered cross-sections along the length of a part are allowed.
3	Multi spindle winding allows for high production rates.
4	Raw material costs can be low
5	Core or mandrel should be extractable, but in some cases the mandrel may become integral to the final part (i.e. a liner in a pressure vessel)
6	Very low fiber angles (less than 5-8 degrees) relative to the length of the part may not be possible (e.g. this may reduce axial length and stiffness)

Resin Transfer Molding (RTM):

A dry fiber preform is placed into a mold, which is then closed. Liquid resin is injected into the mold, infiltrating the preform. The resin is then hardened by heating the mold. Figure 3.2 shows the RTM process. Guidelines for the selection of this process are shown in Table 3.2.

Figure 3.2: RTM

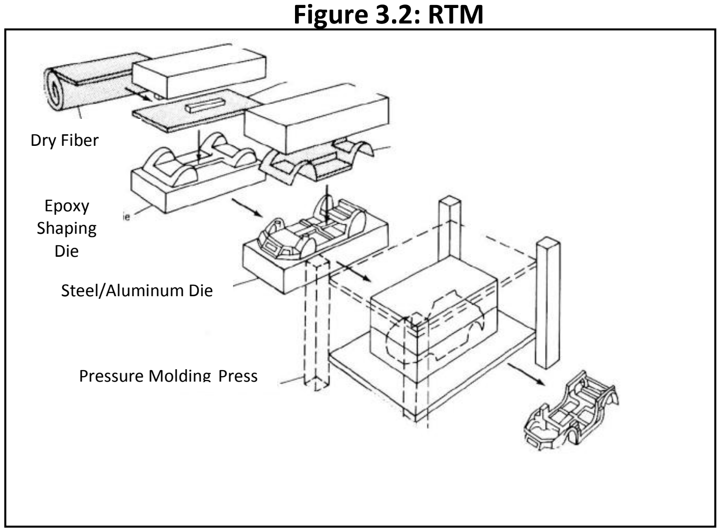


Table 3.2: RTM Selection Guidelines

Item:	Description:
1	Capable of virtually any 3D form, however, as complexity increases so does tooling and fabrication costs.
2	Best method for reducing part count.
3	Lowest cost raw materials (fiber and resin)
4	Tooling costs are typically higher than Filament Winding and Hand Lay-up, and may require longer lead times. Requires a matched mold.
5	Fiber angles anywhere between 0 and 90 degrees are possible.
6	Allows for molded-in features such as bosses, inserts, raceways, etc.
7	Very tight dimensional tolerances on both inside and outside surfaces of the component.
8	Surface finish approaches "Class A"

Hand Lay-up

Composite material is laid into or onto a mold by hand. Fiber orientation is dependent upon the accuracy of the technician doing the lay-up. This process can use a dry fiber preform, which is then wet-out during the layup, or may use prepreg materials. Once the composite material is laid into the mold it is usually vacuum bagged and then oven or autoclave cured. Guidelines for the selection of this process are shown in Table 3.3.

Table 3.3: Hand Lay-up Selection Guidelines

Item:	Description:
1	Virtually no limitations on geometric features.
2	Can be the highest cost raw materials.
3	Fiber angles anywhere between 0 and 90 degrees are possible.
4	Tooling surface typically limited to only one side of the component.
5	Since this is a totally manual process there is more likelihood for "human error" in fabricating production components.
6	This is the highest cost (due to labor intensity) production method.

4. Tolerances and Limits

The three different fabrication techniques are capable of different tolerances. Typical part tolerances are listed in Table 4.1 and are based upon typical commercial grade 12K standard modulus carbon fiber. Tolerance, however, may vary depending upon part complexity, size, thickness, composite material used in the part and the type/cost of the tooling used to fabricate the part.

Table 4.1: General Tolerances and Limits

Item or Feature	Filament Winding	RTM	Hand Lay-up
Minimum Thickness: Quasi Lay-up Uni Lay-up	 0.050 in. 0.009in.	 0.030 in. 0.009 in.	 0.030 in. 0.005 in.
Thickness Tolerance (% of Thickness)	±12%	±2.5%	±12%
Length or Height Tolerance	±0.010 in.	±0.010 in.	±0.010 in.
End Cut Squareness	0.1°	0.1°	0.1°
Profile (tubes) per ft. of Length	0.0025 in.	0.0025 in.	0.0025 in.
Minimum Radius: Standard Modulus: High Modulus	 0.125 in. 0.250 in.	 0.125 in. 0.250 in.	 0.125 in. 0.250 in.
Maximum Continuous Part Length (Limited by equipment)	20 ft.	20 ft.	20 ft.
Maximum Outer Diameter (limited by equipment)	5 ft.	>>5 ft.	>>5 ft.
ID Tolerance (tubes)	±0.006 in.	±0.006 in.	±0.006 in.
OD Tolerance (tubes)	±0.010 in. machined	±0.005 in.	±0.010 in. machined
Location Tolerance of Molded-in or built-in features	±.080 typical	±.040 typical ±.005 possible	±.080 typical ±.005 possible
Lay-up Fiber Orientation Tolerance	±2°	±3°	±3°
Fiber Volume Range	55% - 60%	20% - 62%	55% - 62%
Minimum Fiber Orientation Angle Relative to structural X-direction	5° - 15° (Depends on part diameter) 0° with hand layup	0°	0°

5. Bonded Joints

Adhesive bonded joints in composites are preferred over mechanical fastened (bolted or riveted) for the following reasons:

- Reduces stress concentrations (better transfer of load)
- Lighter weight
- Improved alignment of mating parts
- Easily joins thin sections
- No galvanic corrosion of bolts

Adhesive Joints are strongest when the joint is loaded in shear. Recommended bond line thicknesses are on the order of 0.005 to 0.010 inches. Normal loads which produce peel stresses greatly weaken adhesive joints. Figure 5.1 shows the effect of peel and gives recommendations for limiting peel stresses. Figure 5.2 shows recommended adhesive joint designs.

Figure 5.1
Limiting Peel

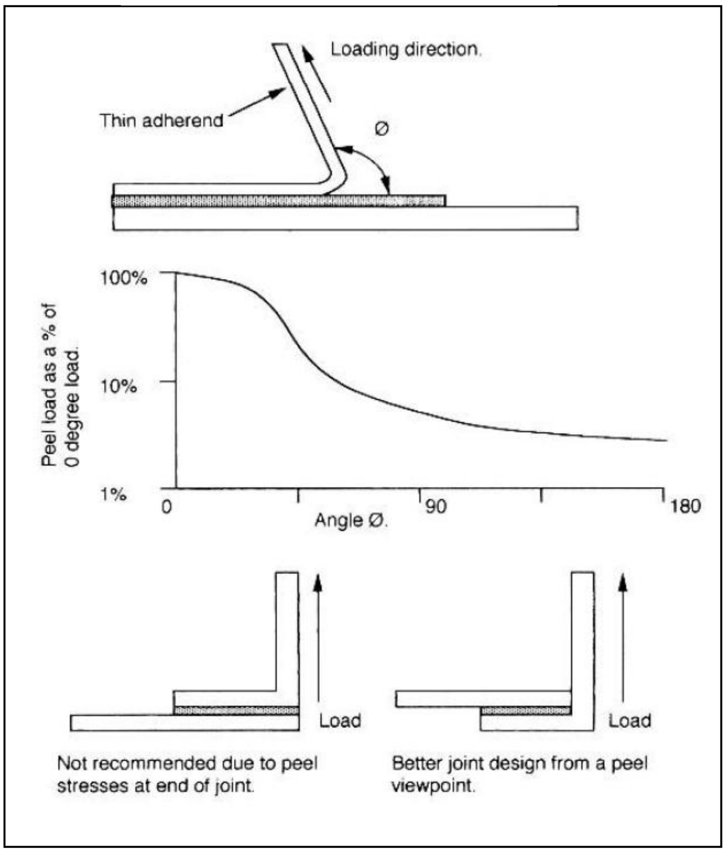
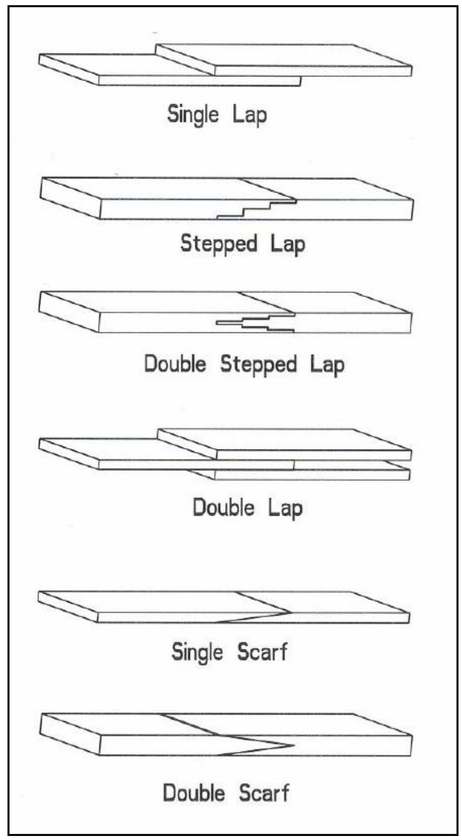


Figure 5.2
Recommended Joint Designs



6. Mechanical Joints

Adhesive bonded joints in composites are preferred over mechanical fastened (bolted or riveted) however; mechanical joints do offer some advantages:

- Allows for disassembly
- Ease of inspection
- Less sensitive to environmental effects

Mechanical joints in composites can exhibit the 6 type of failure modes shown in Figure 6.1. To limit these failures the following rules should be followed (this applies only to mechanical joints which are highly loaded):

- Maintain a free edge distance of 4 times the bolt diameter or greater
- The composite lay-up in the bolted area should be close to quasi-isotropic(0°/45°/-45°/90°)
- Joint design should follow one of the forms shown in Figure 6.2
- Bolt or rivet should fit snug in the hole, since composites do not permanently yield to take up load sharing between bolts.

Figure 6.1
Joint Failure Modes

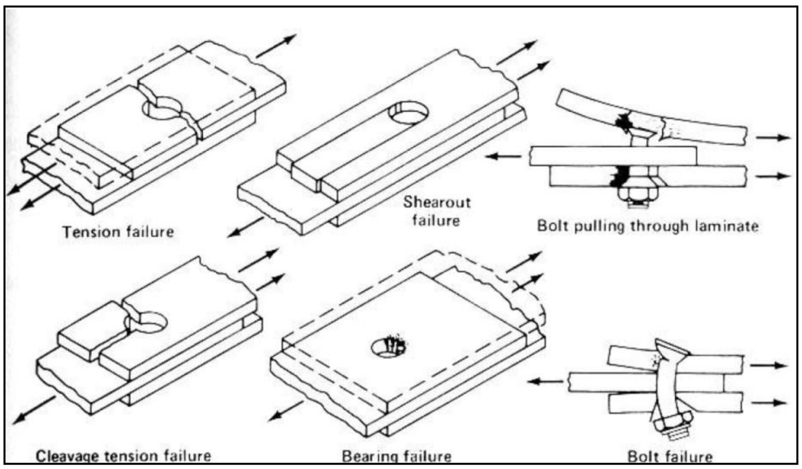
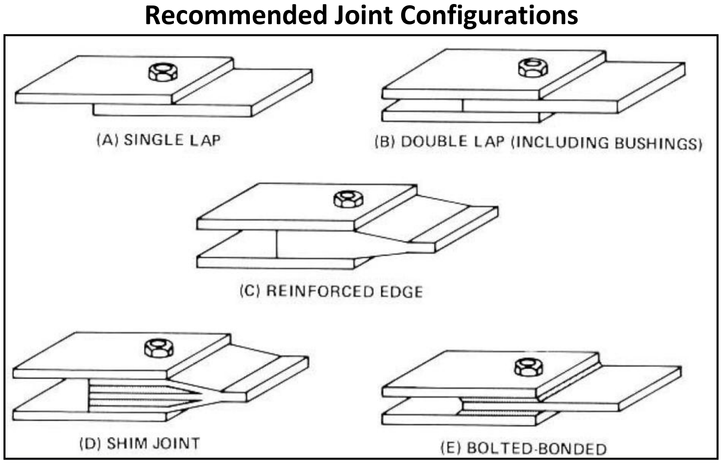


Figure 6.2

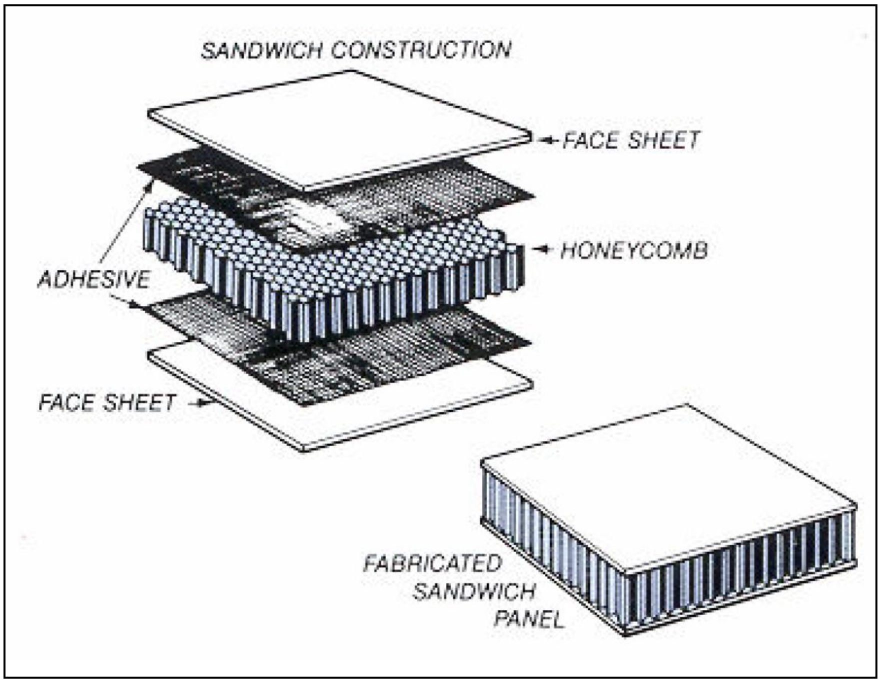
Recommended Joint Configurations



7. Sandwich Structures

Sandwich structures are commonly used in composite structural designs to increase the bending stiffness of a component without adding additional weight. Figure 7.1 illustrates sandwich construction:

Figure 7.1
Sandwich Constructions



The benefit of sandwich construction can be thought of as the same as the advantage of an I-beam, only in plate form. The stiffness advantage of sandwich construction is shown in Figure 7.2:

Figure 7.2
Advantage of Sandwich Construction

	Solid Metal Laminate	Sandwich Construction	Thicker Sandwich
Relative Stiffness	100	700 7 time more rigid	3700 37 times more rigid
Relative Strength	100	350 3.5 times as strong	925 9.25 times as strong
Relative Weight	100	105 5% increase in weight	109 9% increase in weight

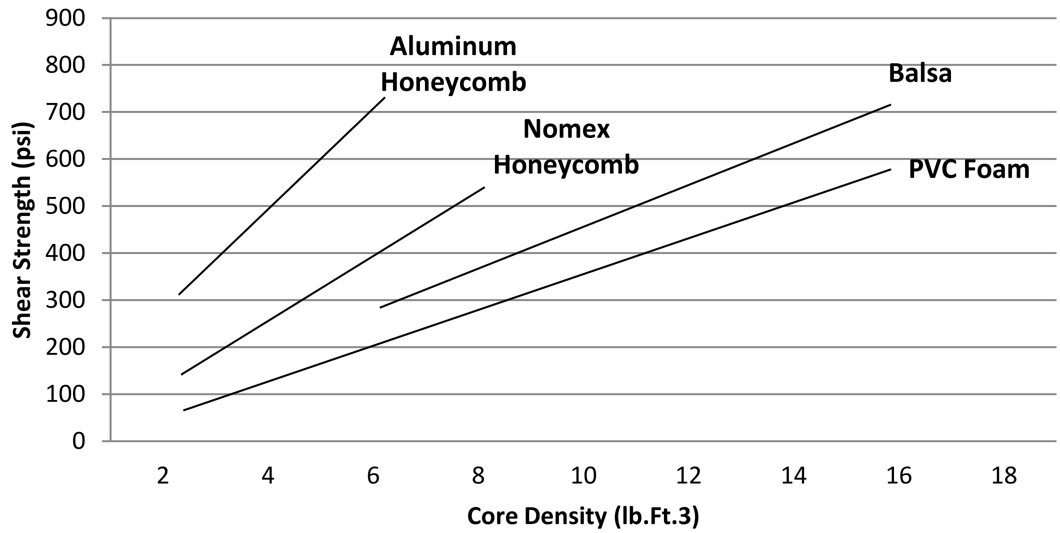
A striking example of how honeycomb stiffens a structure without materially increasing its weight.

The core materials available for sandwich construction are quite diverse. There are essentially three types of core materials:

- Honeycomb (aluminum, carbon and nomex)
- Foam
- Balsa Wood

The function of a core material is to transfer shear loading between the two face sheets. Figure 7.3 shows the shear strength of various cores. Structures lightly loaded in shear can use foam cores, which are the lowest cost core material, followed by balsa and then honeycomb.

Figure 7.3
Shear Strength of Various Cores



8. Composite Component Costs

Factors Contributing to Component Costs:

Components fabricated with composite materials will vary in cost depending upon the following:

- Type of fiber (Standard carbon, Ultra-high carbon, Fiberglass, Kevlar)
- Fiber form (Roving or spooled , Fabric, Braid)
- Type of Resin (High Strain, Flame retardant, Toughened)
- Size
- Complexity (plate, tube, 3D form)
- Tolerances
- Fabrication Method (filament winding, RTM, Lay-up)
- Finishing or cosmetics
- Organizational overhead structure

These nine factors make it most difficult to determine the cost for a generic composite product. Our Composites engineering team can help you to determine a product based upon your requirements.

Don't be fooled by the higher material costs of composites:

Although the material for composites may be higher than most metals, the overall end product cost is what counts! Composites can offer lower component costs for the following reasons:

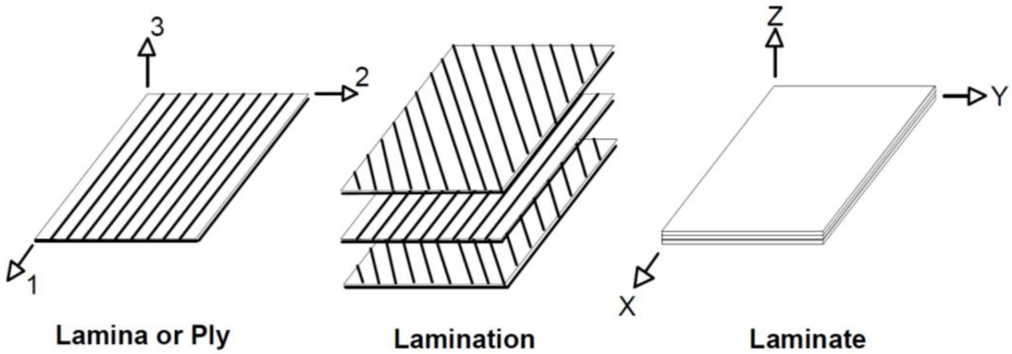
- Lower initial tooling costs
- Consolidation of parts
- Increased life cycle
- Designs which give strength and stiffness only in the directions required

9. Material Property Data Sheets (MPDS)

Introduction:

The following pages tabulate the range of material properties possible for various composite materials. Since composite materials are non-isotropic in nature and are typically composed of a “stack” of uni-directional layers, oriented at different angles, the material properties for a given type of composite material will vary. The process of stacking the various uni-directional layers is called lamination, and is shown schematically in Figure 10.1. The X-direction is defined as the primary structure direction (e.g. for a long tube the X-direction is the axial direction along the tube; the Y-direction is the direction 90° transverse to the X-direction or the circumferential direction around the tube; the Z-direction is the through-the-thickness direction)

Figure 10.1 Composite Lamination



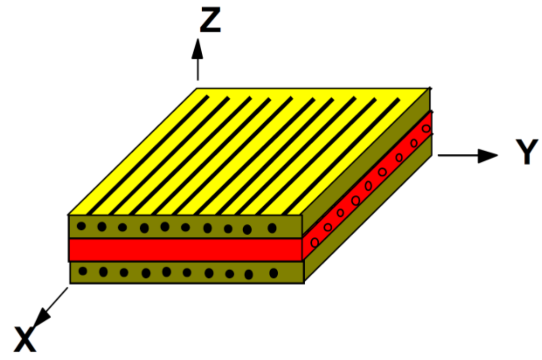
The Tables:

Material properties for the following composite materials are tabulated. A brief description of each material is given:

Material	Comments
E-Glass/Epoxy	Lowest cost of any composite material.
S2-Glass/Epoxy	Highest strength version of fiberglass.
Kevlar 49/Epoxy	Lowest CTE
Standard Modulus Carbon/Epoxy	Lowest cost carbon fiber, most readily available
Intermediate Modulus Carbon/Epoxy	Highest Strength
High Modulus Carbon/Epoxy	Best cost value for high stiffness, very brittle
Very-High Modulus Carbon/Epoxy	High cost, very brittle
Ultra-High Modulus Carbon/Epoxy	Highest cost, very brittle, best thermal conductivity

Nomenclature for the Material Property Data Sheets:

- Predicted material properties for a general composite laminate material having a symmetric lay-up relative to the X-direction of (0°/90°/±45°). All predictions were calculated using CompositePro composites design and analysis software. (www.compositepro.com)
- The **<u>Bold Underlined</u>** Uni, Fabric, Quasi, and Shear lay-ups represent typical laminates for Hand Lay-up, Filament Winding, and TRM fabrication processes, although all the lay-ups shown are possible.



- **Strengths are based upon First Ply failure stresses.** When a laminated composite is loaded it will generally fail on a ply-by-ply basis. That is, as the load increases the weakest ply on the laminate will fail first. The more the fiber in a ply is aligned opposite to the load direction (i.e. the load is in the X-direction but the fiber is aligned in the Y-direction) the more likely it is to fail first. Although it is not really related to yield in a metallic, first ply failure can be loosely thought of as the yield point for a composite. Even though a composite may fail in first-ply failure, it often can carry many times the load beyond first-ply to reach the ultimate failure. ***Call us for more information on Ultimate Failure Strengths.***
- <u>Symbols</u>

Ex = Young's modulus in structural X-direction	νyz = Poisson's Ratio in YZ plane due to a stress in the Y-direction
Ey = Young's modulus in structural Y-direction	νzy = Poisson's Ratio in YZ plane due to a stress in the Z-direction
Ez = Young's modulus in structural Z-direction	αx = Coefficient of Thermal Expansion X-direction
Gxy = Shear Modulus in XY Plane	αy = Coefficient of Thermal Expansion Y-direction
Gxz = Shear Modulus in XZ Plane	αz = Coefficient of Thermal Expansion Z-direction
Gyz = Shear modulus in YZ Plane	+σx = 1st-Ply tensile strength in the X- direction
νxy = poisson's Ration in XY plane due to a stress in the X-direction	-σx = 1st-Ply compression strength in the X-direction
νyx = Posson's Ration in XY plane due to a stress in the Y-direction	+ σy = 1st-Ply tensile strength in the Y-direction
νxz = Poisson's Ratio in XZ plane due to a stress in the X-direction	-σy = 1st- Ply compression strength in the Y-direction
νzx = Poisson's Ration in the XZ plane due to a stress in the Z-direction	τxy = 1st- Ply shear strength in the XY-Plane

Note: all through-the-thickness Z-direction properties are based upon laminated composites in which all fibers are oriented in the XY plane only. No fiber reinforcement is oriented in the Z-axis direction.

Important Step-By-Step Instructions for Using the Material Property Data Sheets (MPDS):

1) Establish the X and Y structural directions for the component to be fabricated.
2) Determine if one of the structural directions does not need to be as strong and/or strain (deflection) limiting as the other direction.

   a) If both the X and Y directions require equal strength and/or deflection limiting then the Bold Underline rows (excluding the Uni row) of the tables represent the properties from which a selection should be made. These lay-ups have a modulus Ratio = 1.0 (see 2b below).

   b) If both the X and Y directions require less strength and/or deflection than the other, then estimate a "Modulus Ratio" for the component and ***select a lay-up from the table which is near that ratio.*** The "Modulus Ratio" is defined as the ratio of the larger modulus divided by the smaller, and will always be 1.0 or greater. If the exact moduli for the componenet are not known, then simply estimate the ratio based upon how the component might be loaded (e.g. the structure needs to carry 3 times as much load in the X-direction; thus, the modulus ratio = 3.) Otherwise, make an educated guess *(Note: when reading the tables, the Modulus Ratio is based upon the X-direction being the more highly loaded direction. Just interchange the X and Y subscripts in the table if the Y-direction is the more highly loaded direction)*

3) Select a given composite material based upon the extensional modulus (Ex or Ey) or strength desired. Different composite materials will yield greater or smaller extensional moduli; examining different MPDS's may be necessary.

4) Finally, the required Shear modulus should be established. Different composite materials will yield greater or smaller shear moduli (Gxy); examining different MPDS's may be necessary.

   a) If an extract required shear modulus is known, then simply choose a lay-up which gives that shear modulus for the modulus ratio calculated in step 3.
   b) If the exact desired shear modulus is not known, then qualitatively determine the structure is highly or lightly loaded in shear. If the structure is highly loaded then choose a higher shear modulus from the tables.

Material Property Data Sheets

Produced Using

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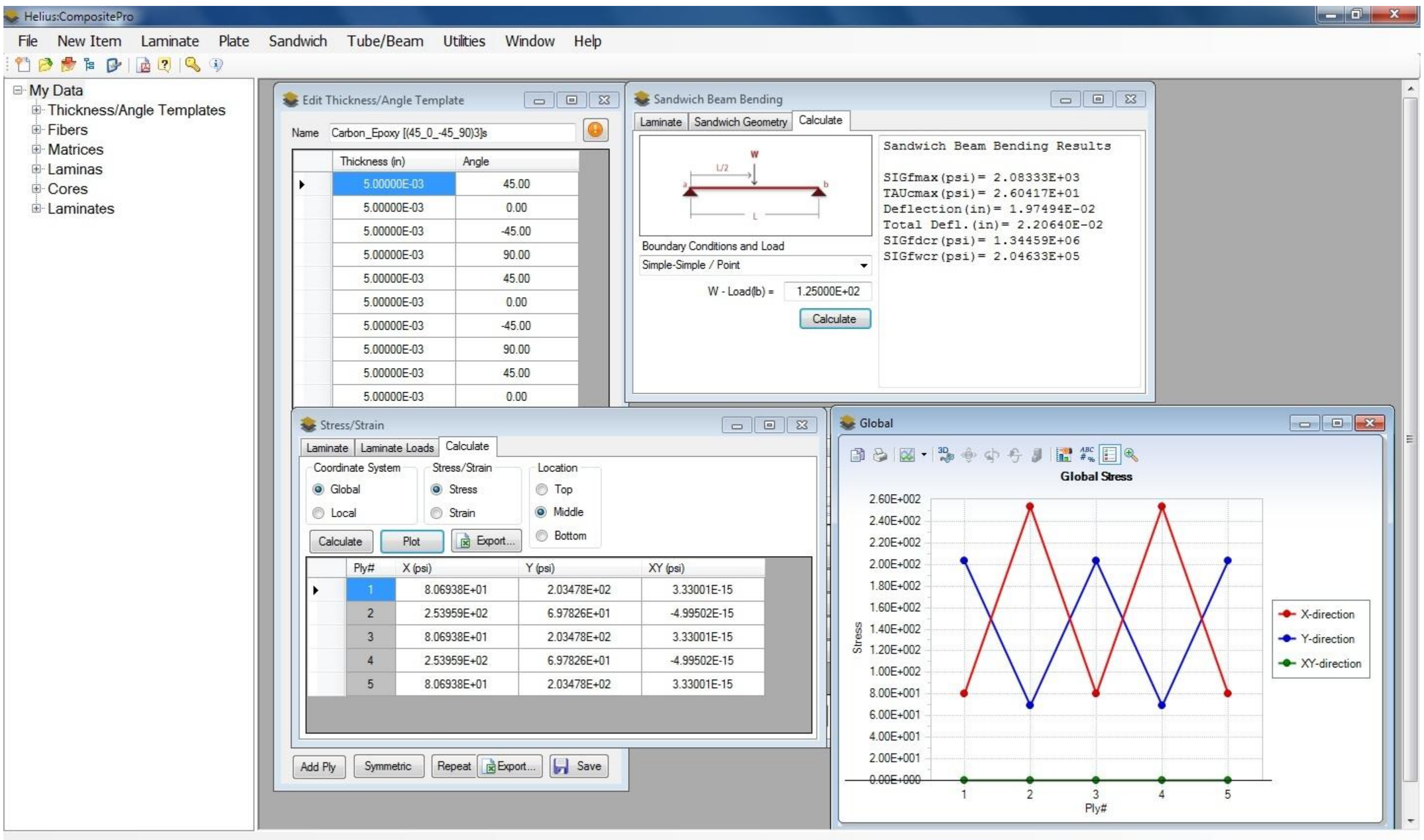

Software for the
Design and Analysis of
Composite Materials and
Structures

2D (XY) Properties & Strengths for E-Glass/Epoxy
(V_f = 60%, Density = 0.075 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	νxy	νyx	αx μ in/in/F	αy μ in/in/F	+σx (ksi)	-σx (ksi)	+σy (ksi)	-σy (ksi)	τxy (ksi)
Uni	**100**	**0**	**0**	**6.50**	**1.80**	**3.61**	**0.80**	**0.280**	**0.078**	**3.746**	**13.370**	**150.15**	**-90.02**	**7.00**	**-20.00**	**10.00**
2	90	10	0	6.05	2.28	2.66	0.80	0.222	0.084	4.173	10.733	23.53	-67.21	8.86	-25.30	10.00
3	90	0	10	6.10	1.91	3.19	0.91	0.315	0.099	3.782	12.383	58.01	-58.01	7.44	-21.25	7.05
4	80	20	0	5.59	2.75	2.03	0.80	0.184	0.091	4.591	9.003	21.74	-62.09	10.71	-30.60	10.00
5	80	10	10	5.66	2.39	2.37	0.91	0.253	0.107	4.253	10.053	22.02	-56.45	9.29	-26.53	7.05
6	80	0	20	5.70	2.02	2.82	1.01	0.345	0.122	3.844	11.509	52.96	-52.96	7.85	-22.43	7.88
7	70	30	0	5.12	3.23	1.59	0.80	0.157	0.099	5.035	7.775	19.92	-56.91	12.57	-35.89	10.00
8	70	20	10	5.21	2.86	1.82	0.91	0.212	0.116	4.720	8.488	20.25	-53.69	11.13	-31.80	7.05
9	70	10	20	5.27	2.49	2.11	1.01	0.281	0.133	4.362	9.429	20.48	-51.38	9.69	-27.48	7.88
10	70	0	30	5.29	2.12	2.50	1.12	0.372	0.149	3.933	10.723	48.23	-48.23	8.24	-23.04	8.71
11	60	40	0	4.65	3.71	1.26	0.80	0.137	0.109	5.537	6.852	18.10	-51.68	14.41	-41.17	10.00
12	60	30	10	4.74	3.34	1.42	0.91	0.182	0.128	5.224	7.355	18.45	-50.16	12.98	-36.96	7.05
13	60	20	20	4.82	2.96	1.63	1.01	0.237	0.146	4.886	8.000	18.74	-48.67	11.52	-32.32	7.88
14	60	10	30	4.87	2.59	1.88	1.12	0.306	0.163	4.505	8.848	18.94	-46.58	10.06	-27.80	8.71
15	60	0	40	4.89	2.21	2.21	1.23	0.396	0.179	4.054	10.005	43.75	-43.75	8.59	-23.40	9.53
Fabric	**50**	**50**	**0**	**4.18**	**4.18**	**1.00**	**0.80**	**0.121**	**0.121**	**6.128**	**6.128**	**16.26**	**-46.43**	**16.26**	**-46.43**	**10.00**
17	50	40	10	4.28	3.81	1.12	0.91	0.160	0.142	5.800	6.491	16.64	-46.10	14.81	-41.67	7.05
18	50	30	20	4.36	3.43	1.27	1.01	0.205	0.161	5.460	6.947	16.96	-45.23	13.35	-36.93	7.88
19	50	20	30	4.43	3.05	1.45	1.12	0.260	0.180	5.095	7.531	17.22	-43.90	11.87	-32.35	8.71
20	50	10	40	4.47	2.67	1.67	1.23	0.329	0.197	4.688	8.297	17.38	-42.01	10.39	-27.89	9.53
21	50	0	50	4.47	2.29	1.96	1.33	0.417	0.213	4.213	9.338	39.47	-39.47	8.89	-23.56	10.36
22	**40**	**40**	**20**	**3.90**	**3.90**	**1.00**	**1.01**	**0.181**	**0.181**	**6.128**	**6.128**	**15.16**	**-41.27**	**15.16**	**-41.27**	**7.88**
23	40	30	30	3.97	3.52	1.13	1.12	0.227	0.200	5.755	6.541	15.46	-40.50	13.68	-36.61	8.71
24	40	20	40	4.03	3.13	1.29	1.23	0.282	0.219	5.359	7.070	15.68	-39.32	12.18	-32.10	9.53
25	40	10	50	4.06	2.74	1.48	1.33	0.350	0.236	4.923	7.764	15.81	-37.63	10.67	-27.73	10.36
26	40	0	60	4.06	2.35	1.73	1.44	0.436	0.253	4.417	8.706	35.35	-35.35	9.15	-23.47	11.19
27	**30**	**30**	**40**	**3.58**	**3.58**	**1.00**	**1.23**	**0.246**	**0.246**	**6.128**	**6.128**	**13.95**	**-35.95**	**13.95**	**-35.95**	**9.53**
28	30	20	50	3.63	3.19	1.14	1.33	0.302	0.265	5.695	6.608	14.14	-34.90	12.42	-31.55	10.36
29	30	10	60	3.66	2.80	1.31	1.44	0.369	0.282	5.223	7.237	14.23	-33.40	10.88	-27.27	11.19
30	30	0	70	3.65	2.40	1.52	1.54	0.454	0.299	4.682	8.091	31.36	-31.28	9.34	-23.11	12.02
Quasi	**20**	**20**	**60**	**3.23**	**3.23**	**1.00**	**1.44**	**0.320**	**0.320**	**6.128**	**6.128**	**12.58**	**-30.63**	**12.58**	**-30.63**	**11.19**
32	20	10	70	3.25	2.83	1.15	1.54	0.387	0.337	5.612	6.699	12.65	-29.30	11.02	-26.49	12.02
33	20	0	80	3.23	2.43	1.33	1.65	0.469	0.353	5.028	7.476	27.49	-26.78	9.45	-22.44	12.84
34	10	10	80	2.84	2.84	1.00	1.65	0.403	0.403	6.128	6.128	11.05	-25.32	11.05	-25.32	12.84
35	10	0	90	2.81	2.43	1.16	1.76	0.484	0.418	5.490	6.834	23.70	-22.63	9.45	-21.43	13.67
Shear	**0**	**0**	**100**	**2.39**	**2.39**	**1.00**	**1.86**	**0.497**	**0.497**	**6.128**	**6.128**	**20.00**	**-20.00**	**20.00**	**-20.00**	**14.50**

Based upon Owens Corning E-glass with Hexcel 3501-6 350°F epoxy   Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for E-Glass/Epoxy
(V_f = 60%, Density = 0.075 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	ν_{xz}	ν_{zx}	ν_{yz}	ν_{zy}	α_z μ in/in/F
Uni	**100**	**0**	**0**	**1.80**	**0.80**	**0.52**	**0.280**	**0.078**	**0.360**	**0.360**	**13.370**
2	90	10	0	1.85	0.77	0.55	0.303	0.092	0.358	0.290	14.234
3	90	0	10	1.82	0.79	0.54	0.266	0.079	0.352	0.335	13.742
4	80	20	0	1.88	0.74	0.58	0.318	0.107	0.355	0.242	14.747
5	80	10	10	1.86	0.76	0.56	0.291	0.096	0.349	0.272	14.468
6	80	0	20	1.84	0.77	0.55	0.255	0.082	0.343	0.312	14.059
7	70	30	0	1.89	0.72	0.61	0.328	0.121	0.351	0.206	15.053
8	70	20	10	1.88	0.73	0.59	0.307	0.111	0.345	0.227	14.898
9	70	10	20	1.87	0.74	0.58	0.280	0.099	0.338	0.254	14.670
10	70	0	30	1.85	0.76	0.56	0.244	0.085	0.332	0.291	14.332
11	60	40	0	1.90	0.69	0.63	0.336	0.138	0.347	0.178	15.218
12	60	30	10	1.90	0.70	0.62	0.319	0.128	0.340	0.194	15.143
13	60	20	20	1.89	0.72	0.61	0.297	0.117	0.333	0.213	15.024
14	60	10	30	1.88	0.73	0.59	0.270	0.104	0.327	0.238	14.841
15	60	0	40	1.87	0.74	0.58	0.235	0.090	0.320	0.271	14.565
Fabric	**50**	**50**	**0**	**1.91**	**0.66**	**0.66**	**0.343**	**0.156**	**0.343**	**0.156**	**15.270**
17	50	40	10	1.91	0.67	0.65	0.328	0.146	0.335	0.167	15.256
18	50	30	20	1.90	0.69	0.63	0.310	0.135	0.327	0.181	15.211
19	50	20	30	1.90	0.70	0.62	0.288	0.124	0.320	0.199	15.125
20	50	10	40	1.89	0.72	0.61	0.261	0.110	0.313	0.222	14.985
21	50	0	50	1.88	0.73	0.59	0.227	0.095	0.307	0.252	14.764
22	**40**	**40**	**20**	**1.91**	**0.66**	**0.66**	**0.319**	**0.156**	**0.319**	**0.156**	**15.270**
23	40	30	30	1.91	0.67	0.65	0.301	0.145	0.312	0.169	15.254
24	40	20	40	1.90	0.69	0.63	0.280	0.132	0.305	0.185	15.202
25	40	10	50	1.90	0.70	0.62	0.253	0.118	0.298	0.206	15.101
26	40	0	60	1.89	0.72	0.61	0.219	0.102	0.292	0.234	14.931
27	**30**	**30**	**40**	**1.91**	**0.66**	**0.66**	**0.294**	**0.156**	**0.294**	**0.156**	**15.270**
28	30	20	50	1.91	0.67	0.65	0.272	0.143	0.287	0.171	15.252
29	30	10	60	1.90	0.69	0.63	0.246	0.128	0.280	0.190	15.190
30	30	0	70	1.89	0.70	0.62	0.213	0.111	0.274	0.216	15.068
Quasi	**20**	**20**	**60**	**1.91**	**0.66**	**0.66**	**0.265**	**0.156**	**0.265**	**0.156**	**15.270**
32	20	10	70	1.91	0.67	0.65	0.239	0.140	0.259	0.174	15.248
33	20	0	80	1.90	0.69	0.63	0.207	0.122	0.252	0.198	15.173
34	10	10	80	1.91	0.66	0.66	0.233	0.156	0.233	0.156	15.270
35	10	0	90	1.90	0.67	0.65	0.201	0.136	0.227	0.178	15.243
Shear	**0**	**0**	**100**	**1.91**	**0.66**	**0.66**	**0.196**	**0.156**	**0.196**	**0.156**	**15.270**

Based upon Owens Corning E-glass with Hexcel 3501-6 350°F epoxy

2D (XY) Properties & Strengths for S2-Glass/Epoxy
(V_f = 62%, Density = 0.072 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	ν_{xy}	ν_{yx}	α_x μ in/in/F	α_y μ in/in/F	$+\sigma_x$ (ksi)	$-\sigma_x$ (ksi)	$+\sigma_y$ (ksi)	$-\sigma_y$ (ksi)	τ_{xy} (ksi)
Uni	**100**	**0**	**0**	**8.10**	**2.60**	**3.12**	**0.90**	**0.270**	**0.087**	**1.585**	**12.410**	**259.50**	**-103.80**	**9.00**	**-22.49**	**13.50**
2	90	10	0	7.57	3.16	2.40	0.90	0.223	0.093	2.104	9.752	26.19	-65.49	10.93	-27.32	13.50
3	90	0	10	7.60	2.70	2.81	1.05	0.310	0.110	1.615	11.507	76.18	-84.77	9.34	-23.36	7.25
4	80	20	0	7.03	3.72	1.89	0.90	0.190	0.100	2.626	7.884	24.33	-60.82	12.86	-32.15	13.50
5	80	10	10	7.08	3.26	2.17	1.05	0.258	0.119	2.195	9.068	24.49	-61.22	11.27	-28.17	7.25
6	80	0	20	7.08	2.79	2.54	1.20	0.346	0.136	1.674	10.673	74.99	-70.76	9.66	-24.14	8.28
7	70	30	0	6.49	4.27	1.52	0.90	0.165	0.109	3.185	6.493	22.44	-56.10	14.79	-36.97	13.50
8	70	20	10	6.55	3.81	1.72	1.05	0.221	0.129	2.782	7.327	22.65	-56.63	13.19	-32.96	7.25
9	70	10	20	6.58	3.34	1.97	1.20	0.291	0.148	2.321	8.418	22.76	-56.89	11.57	-28.92	8.28
10	70	0	30	6.56	2.87	2.29	1.34	0.380	0.166	1.767	9.894	71.37	-59.83	9.93	-24.83	9.30
11	60	40	0	5.94	4.83	1.23	0.90	0.146	0.119	3.811	5.411	20.54	-51.35	16.71	-41.78	13.50
12	60	30	10	6.01	4.36	1.38	1.05	0.193	0.140	3.416	6.015	20.79	-51.96	15.10	-37.75	7.25
13	60	20	20	6.05	3.89	1.56	1.20	0.250	0.161	2.983	6.785	20.95	-52.37	13.47	-33.67	8.28
14	60	10	30	6.07	3.42	1.78	1.34	0.321	0.180	2.489	7.792	21.00	-52.50	11.82	-29.55	9.30
15	60	0	40	6.04	2.94	2.06	1.49	0.410	0.199	1.899	9.155	64.24	-50.96	10.16	-25.39	10.32
Fabric	**50**	**50**	**0**	**5.38**	**5.38**	**1.00**	**0.90**	**0.131**	**0.131**	**4.538**	**4.538**	**18.63**	**-46.57**	**18.63**	**-46.57**	**13.50**
17	50	40	10	5.46	4.91	1.11	1.05	0.172	0.154	4.134	4.980	18.90	-47.25	17.01	-42.51	7.25
18	50	30	20	5.52	4.44	1.24	1.20	0.220	0.177	3.706	5.536	19.11	-47.77	15.36	-38.40	8.28
19	50	20	30	5.56	3.96	1.40	1.34	0.278	0.198	3.239	6.247	19.22	-48.06	13.70	-34.25	9.30
20	50	10	40	5.56	3.47	1.60	1.49	0.349	0.218	2.709	7.179	19.22	-48.06	12.02	-30.05	10.32
21	50	0	50	5.51	2.98	1.85	1.64	0.438	0.237	2.079	8.443	57.45	-43.51	10.33	-25.81	11.35
22	**40**	**40**	**20**	**4.98**	**4.98**	**1.00**	**1.20**	**0.196**	**0.196**	**4.538**	**4.538**	**17.24**	**-43.11**	**17.24**	**-43.11**	**8.28**
23	40	30	30	5.03	4.50	1.12	1.34	0.245	0.219	4.072	5.048	17.41	-43.52	15.56	-38.91	9.30
24	40	20	40	5.05	4.01	1.26	1.49	0.303	0.241	3.566	5.704	17.48	-43.70	13.87	-34.67	10.32
25	40	10	50	5.04	3.51	1.43	1.64	0.375	0.261	2.996	6.567	17.43	-43.57	12.15	-30.38	11.35
26	40	0	60	4.97	3.01	1.65	1.79	0.464	0.281	2.320	7.742	50.95	-37.09	10.42	-26.06	12.37
27	**30**	**30**	**40**	**4.53**	**4.53**	**1.00**	**1.49**	**0.268**	**0.268**	**4.538**	**4.538**	**15.69**	**-39.23**	**15.69**	**-39.23**	**10.32**
28	30	20	50	4.54	4.03	1.13	1.64	0.327	0.291	3.988	5.141	15.72	-39.29	13.95	-34.88	11.35
29	30	10	60	4.51	3.53	1.28	1.79	0.399	0.312	3.370	5.939	15.61	-39.03	12.20	-30.50	12.37
30	30	0	70	4.43	3.02	1.47	1.94	0.488	0.332	2.641	7.034	44.68	-31.44	10.43	-26.08	13.40
Quasi	**20**	**20**	**60**	**4.03**	**4.03**	**1.00**	**1.79**	**0.350**	**0.350**	**4.538**	**4.538**	**13.94**	**-34.84**	**13.94**	**-34.84**	**12.37**
32	20	10	70	3.98	3.51	1.14	1.94	0.422	0.371	3.866	5.274	13.78	-32.69	12.14	-30.35	13.40
33	20	0	80	3.89	2.99	1.30	2.08	0.510	0.392	3.075	6.294	38.62	-26.38	10.33	-25.83	14.42
34	10	10	80	3.45	3.45	1.00	2.08	0.443	0.443	4.538	4.538	11.94	-26.96	11.94	-26.96	14.42
35	10	0	90	3.34	2.92	1.15	2.23	0.531	0.463	3.675	5.483	32.73	-21.78	10.09	-25.22	15.44
Shear	**0**	**0**	**100**	**2.79**	**2.79**	**1.00**	**2.38**	**0.550**	**0.550**	**4.538**	**4.538**	**27.00**	**-27.00**	**27.00**	**-27.00**	**16.47**

Based upon Owens Corning S2-glass with generic 350°F epoxy

Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for S2-Glass/Epoxy
(V_f = 62%, Density = 0.072 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	ν_{xz}	ν_{zx}	ν_{yz}	ν_{zy}	α_z μ in/in/F
Uni	**100**	**0**	**0**	**2.60**	**0.90**	**0.56**	**0.270**	**0.087**	**0.353**	**0.353**	**12.410**
2	90	10	0	2.65	0.87	0.60	0.290	0.102	0.350	0.294	13.250
3	90	0	10	2.62	0.88	0.58	0.255	0.088	0.344	0.334	12.753
4	80	20	0	2.69	0.83	0.63	0.304	0.116	0.346	0.250	13.778
5	80	10	10	2.67	0.85	0.61	0.277	0.104	0.339	0.278	13.483
6	80	0	20	2.64	0.87	0.60	0.242	0.090	0.333	0.315	13.057
7	70	30	0	2.71	0.80	0.67	0.314	0.132	0.341	0.217	14.105
8	70	20	10	2.70	0.82	0.65	0.292	0.121	0.334	0.237	13.935
9	70	10	20	2.68	0.83	0.63	0.265	0.108	0.328	0.263	13.688
10	70	0	30	2.66	0.85	0.61	0.230	0.093	0.322	0.298	13.326
11	60	40	0	2.73	0.77	0.70	0.323	0.148	0.336	0.190	14.284
12	60	30	10	2.72	0.78	0.68	0.304	0.138	0.329	0.205	14.202
13	60	20	20	2.71	0.80	0.67	0.282	0.126	0.321	0.224	14.070
14	60	10	30	2.70	0.82	0.65	0.254	0.113	0.315	0.248	13.868
15	60	0	40	2.68	0.83	0.63	0.219	0.097	0.308	0.281	13.564
Fabric	**50**	**50**	**0**	**2.73**	**0.73**	**0.73**	**0.330**	**0.167**	**0.330**	**0.167**	**14.341**
17	50	40	10	2.73	0.75	0.72	0.314	0.157	0.322	0.179	14.326
18	50	30	20	2.73	0.77	0.70	0.295	0.146	0.314	0.193	14.276
19	50	20	30	2.72	0.78	0.68	0.272	0.133	0.307	0.211	14.180
20	50	10	40	2.71	0.80	0.67	0.244	0.119	0.300	0.234	14.022
21	50	0	50	2.69	0.82	0.65	0.209	0.102	0.293	0.264	13.773
22	**40**	**40**	**20**	**2.73**	**0.73**	**0.73**	**0.305**	**0.167**	**0.305**	**0.167**	**14.341**
23	40	30	30	2.73	0.75	0.72	0.286	0.155	0.297	0.180	14.323
24	40	20	40	2.72	0.77	0.70	0.263	0.142	0.290	0.197	14.265
25	40	10	50	2.72	0.78	0.68	0.235	0.127	0.283	0.219	14.150
26	40	0	60	2.70	0.80	0.67	0.200	0.109	0.276	0.248	13.954
27	**30**	**30**	**40**	**2.73**	**0.73**	**0.73**	**0.278**	**0.167**	**0.278**	**0.167**	**14.341**
28	30	20	50	2.73	0.75	0.72	0.255	0.153	0.270	0.183	14.320
29	30	10	60	2.72	0.77	0.70	0.227	0.137	0.263	0.203	14.249
30	30	0	70	2.71	0.78	0.68	0.192	0.118	0.256	0.230	14.106
Quasi	**20**	**20**	**60**	**2.73**	**0.73**	**0.73**	**0.247**	**0.167**	**0.247**	**0.167**	**14.341**
32	20	10	70	2.73	0.75	0.72	0.219	0.150	0.240	0.186	14.316
33	20	0	80	2.72	0.77	0.70	0.184	0.129	0.233	0.212	14.226
34	10	10	80	2.73	0.73	0.73	0.212	0.167	0.212	0.167	14.341
35	10	0	90	2.73	0.75	0.72	0.177	0.145	0.205	0.192	14.309
Shear	**0**	**0**	**100**	**2.73**	**0.73**	**0.73**	**0.171**	**0.167**	**0.171**	**0.167**	**14.341**

Based upon Owens Corning S2-glass with generic 350°F epoxy

2D (XY) Properties & Strengths for Kevlar-49/Epoxy
(V_f = 60%, Density = 0.050 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	ν_{xy}	ν_{yx}	α_x μ in/in/F	α_y μ in/in/F	$+\sigma_x$ (ksi)	$-\sigma_x$ (ksi)	$+\sigma_y$ (ksi)	$-\sigma_y$ (ksi)	τ_{xy} (ksi)
Uni	**100**	**0**	**0**	**11.00**	**0.80**	**13.75**	**0.30**	**0.340**	**0.025**	**-2.200**	**32.000**	**199.98**	**-40.00**	**4.30**	**-20.00**	**9.00**
2	90	10	0	10.02	1.83	5.48	0.30	0.149	0.027	-1.467	11.731	53.88	-36.45	9.83	-6.65	9.00
3	90	0	10	10.06	1.04	9.67	0.55	0.495	0.051	-2.489	22.941	182.96	-36.59	5.59	-7.97	4.03
4	80	20	0	9.01	2.86	3.15	0.30	0.096	0.030	-1.009	6.048	48.43	-32.76	15.35	-10.38	9.00
5	80	10	10	9.16	2.07	4.44	0.55	0.252	0.057	-1.562	9.500	49.25	-33.32	11.10	-7.51	4.03
6	80	0	20	9.10	1.26	7.20	0.81	0.589	0.082	-2.637	17.465	165.38	-33.08	6.79	-10.01	5.87
7	70	30	0	7.99	3.88	2.06	0.30	0.070	0.034	-0.537	3.367	42.94	-29.04	20.87	-14.12	9.00
8	70	20	10	8.18	3.09	2.65	0.55	0.169	0.064	-0.972	4.966	43.96	-29.74	16.61	-11.24	4.03
9	70	10	20	8.27	2.28	3.62	0.81	0.332	0.092	-1.586	7.759	44.45	-30.07	12.28	-8.31	5.87
10	70	0	30	8.11	1.47	5.53	1.06	0.652	0.118	-2.705	13.780	147.34	-29.50	7.88	-12.09	7.72
11	60	40	0	6.96	4.91	1.42	0.30	0.056	0.039	0.031	1.802	37.43	-25.32	26.39	-17.85	9.00
12	60	30	10	7.17	4.11	1.74	0.55	0.127	0.073	-0.379	2.677	38.55	-26.08	22.12	-14.96	4.03
13	60	20	20	7.32	3.30	2.22	0.81	0.231	0.104	-0.870	4.030	39.34	-26.61	17.76	-12.01	5.87
14	60	10	30	7.35	2.48	2.97	1.06	0.396	0.133	-1.545	6.344	39.51	-26.73	13.32	-9.01	7.72
15	60	0	40	7.12	1.64	4.34	1.32	0.697	0.161	-2.717	11.113	125.87	-25.89	8.82	-14.22	9.56
Fabric	**50**	**50**	**0**	**5.94**	**5.94**	**1.00**	**0.30**	**0.046**	**0.046**	**0.770**	**0.770**	**31.91**	**-21.59**	**31.91**	**-21.59**	**9.00**
17	50	40	10	6.16	5.14	1.20	0.55	0.102	0.085	0.334	1.285	33.09	-22.39	27.61	-18.68	4.03
18	50	30	20	6.33	4.32	1.47	0.81	0.177	0.121	-0.136	2.035	34.04	-23.03	23.22	-15.71	5.87
19	50	20	30	6.44	3.49	1.85	1.06	0.284	0.154	-0.689	3.191	34.60	-23.41	18.74	-12.68	7.72
20	50	10	40	6.41	2.64	2.43	1.32	0.448	0.184	-1.432	5.146	34.48	-23.32	14.19	-9.60	9.56
21	50	0	50	6.12	1.78	3.44	1.57	0.732	0.213	-2.677	9.071	106.10	-22.27	9.57	-16.45	11.41
22	**40**	**40**	**20**	**5.33**	**5.33**	**1.00**	**0.81**	**0.144**	**0.144**	**0.770**	**0.770**	**28.65**	**-19.38**	**28.65**	**-19.38**	**5.87**
23	40	30	30	5.47	4.49	1.22	1.06	0.222	0.182	0.226	1.412	29.42	-19.90	24.11	-16.31	7.72
24	40	20	40	5.54	3.63	1.53	1.32	0.330	0.216	-0.401	2.405	29.77	-20.14	19.50	-13.19	9.56
25	40	10	50	5.47	2.76	1.98	1.57	0.492	0.248	-1.226	4.083	29.38	-19.87	14.81	-10.02	11.41
26	40	0	60	5.12	1.87	2.74	1.82	0.758	0.277	-2.578	7.423	87.40	-18.62	10.06	-18.83	13.25
27	**30**	**30**	**40**	**4.60**	**4.60**	**1.00**	**1.32**	**0.261**	**0.261**	**0.770**	**0.770**	**24.71**	**-16.72**	**24.71**	**-16.72**	**9.56**
28	30	20	50	4.62	3.71	1.25	1.57	0.370	0.297	0.048	1.623	24.85	-16.81	19.93	-13.48	11.41
29	30	10	60	4.51	2.81	1.61	1.82	0.529	0.329	-0.884	3.079	24.22	-16.38	15.09	-10.21	13.25
30	30	0	70	4.12	1.89	2.17	2.08	0.780	0.359	-2.391	6.015	69.41	-14.97	10.18	-21.49	15.10
Quasi	**20**	**20**	**60**	**3.70**	**3.70**	**1.00**	**1.82**	**0.406**	**0.406**	**0.770**	**0.770**	**19.88**	**-13.45**	**19.88**	**-13.45**	**13.25**
32	20	10	70	3.54	2.76	1.28	2.08	0.560	0.437	-0.305	2.039	19.02	-12.87	14.85	-10.04	15.10
33	20	0	80	3.11	1.82	1.71	2.33	0.797	0.466	-2.046	4.702	51.94	-11.31	9.77	-24.74	16.95
34	10	10	80	2.56	2.56	1.00	2.33	0.588	0.588	0.770	0.770	13.79	-9.33	13.79	-9.33	16.95
35	10	0	90	2.10	1.59	1.33	2.58	0.812	0.612	-1.330	3.248	34.83	-7.65	8.52	-29.51	18.79
Shear	**0**	**0**	**100**	**1.09**	**1.09**	**1.00**	**2.84**	**0.824**	**0.824**	**0.770**	**0.770**	**18.00**	**-18.00**	**18.00**	**-18.00**	**20.64**

Based upon Dupont Kevlar-49 fiber with Hexcel 3501-6 350°F epoxy

Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for Kevlar-49/Epoxy
(V_f = 60%, Density = 0.050 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	νxz	νzx	νyz	νzy	αz μ in/in/F
Uni	**100**	**0**	**0**	**0.80**	**0.30**	**0.22**	**0.340**	**0.025**	**0.471**	**0.471**	**32.000**
2	90	10	0	0.91	0.29	0.23	0.430	0.039	0.472	0.236	41.406
3	90	0	10	0.85	0.30	0.23	0.264	0.022	0.459	0.375	36.501
4	80	20	0	0.95	0.28	0.24	0.454	0.048	0.473	0.157	43.922
5	80	10	10	0.93	0.29	0.24	0.379	0.038	0.458	0.206	42.526
6	80	0	20	0.88	0.29	0.23	0.216	0.021	0.445	0.311	39.209
7	70	30	0	0.96	0.28	0.25	0.464	0.056	0.473	0.117	44.986
8	70	20	10	0.95	0.28	0.24	0.417	0.049	0.457	0.141	44.426
9	70	10	20	0.94	0.28	0.24	0.338	0.038	0.442	0.182	43.376
10	70	0	30	0.91	0.29	0.24	0.184	0.021	0.428	0.264	41.016
11	60	40	0	0.97	0.27	0.25	0.469	0.065	0.472	0.093	45.466
12	60	30	10	0.97	0.27	0.25	0.435	0.059	0.455	0.107	45.242
13	60	20	20	0.96	0.28	0.25	0.385	0.051	0.438	0.127	44.827
14	60	10	30	0.95	0.28	0.24	0.306	0.039	0.422	0.162	44.038
15	60	0	40	0.92	0.28	0.24	0.160	0.021	0.407	0.229	42.305
Fabric	**50**	**50**	**0**	**0.97**	**0.26**	**0.26**	**0.471**	**0.077**	**0.471**	**0.077**	**45.607**
17	50	40	10	0.97	0.27	0.26	0.445	0.070	0.451	0.085	45.569
18	50	30	20	0.97	0.27	0.25	0.409	0.063	0.432	0.097	45.434
19	50	20	30	0.97	0.27	0.25	0.358	0.054	0.414	0.115	45.144
20	50	10	40	0.96	0.28	0.25	0.279	0.042	0.398	0.144	44.560
21	50	0	50	0.94	0.28	0.24	0.142	0.022	0.383	0.202	43.270
22	**40**	**40**	**20**	**0.97**	**0.26**	**0.26**	**0.423**	**0.077**	**0.423**	**0.077**	**45.607**
23	40	30	30	0.97	0.27	0.26	0.386	0.069	0.403	0.087	45.560
24	40	20	40	0.97	0.27	0.25	0.334	0.058	0.385	0.103	45.384
25	40	10	50	0.96	0.27	0.25	0.256	0.045	0.368	0.129	44.973
26	40	0	60	0.95	0.28	0.25	0.127	0.023	0.352	0.178	44.015
27	**30**	**30**	**40**	**0.97**	**0.26**	**0.26**	**0.365**	**0.077**	**0.365**	**0.077**	**45.607**
28	30	20	50	0.97	0.27	0.26	0.313	0.066	0.346	0.091	45.544
29	30	10	60	0.97	0.27	0.25	0.236	0.051	0.329	0.113	45.291
30	30	0	70	0.96	0.27	0.25	0.114	0.027	0.313	0.158	44.604
Quasi	**20**	**20**	**60**	**0.97**	**0.26**	**0.26**	**0.294**	**0.077**	**0.294**	**0.077**	**45.607**
32	20	10	70	0.97	0.27	0.26	0.219	0.060	0.276	0.097	45.514
33	20	0	80	0.96	0.27	0.25	0.104	0.032	0.261	0.138	45.070
34	10	10	80	0.97	0.26	0.26	0.204	0.077	0.204	0.077	45.607
35	10	0	90	0.97	0.27	0.26	0.095	0.044	0.190	0.116	45.425
Shear	**0**	**0**	**100**	**0.97**	**0.26**	**0.26**	**0.087**	**0.077**	**0.087**	**0.077**	**45.607**

Based upon Dupont Kevlar-49 fiber with Hexcel 3501-6 350°F epoxy

2D (XY) Properties & Strengths for Standard Modulus Carbon/Epoxy
(V_f = 62%, Density = 0.056 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	νxy	νyx	αx μ in/in/F	αy μ in/in/F	+σx (ksi)	-σx (ksi)	+σy (ksi)	-σy (ksi)	τxy (ksi)
Uni	**100**	**0**	**0**	**21.00**	**1.40**	**15.00**	**0.85**	**0.250**	**0.017**	**-0.044**	**12.000**	**315.00**	**-249.90**	**7.80**	**-23.38**	**12.58**
2	90	10	0	19.08	3.37	5.67	0.85	0.104	0.018	0.159	4.576	106.29	-227.09	18.76	-40.07	12.58
3	90	0	10	19.30	1.90	10.18	1.31	0.420	0.041	-0.147	8.442	201.15	-201.15	10.56	-26.96	14.59
4	80	20	0	17.13	5.34	3.21	0.85	0.066	0.020	0.296	2.627	95.40	-203.83	29.72	-63.49	12.58
5	80	10	10	17.51	3.86	4.53	1.31	0.208	0.046	0.128	3.774	97.51	-208.33	21.51	-45.95	14.59
6	80	0	20	17.54	2.37	7.41	1.77	0.518	0.070	-0.192	6.413	171.05	-171.05	13.18	-32.73	19.71
7	70	30	0	15.17	7.30	2.08	0.85	0.048	0.023	0.445	1.727	84.48	-180.48	40.67	-86.90	12.58
8	70	20	10	15.60	5.83	2.68	1.31	0.138	0.052	0.309	2.252	86.87	-185.59	32.44	-69.31	14.59
9	70	10	20	15.87	4.32	3.67	1.77	0.287	0.078	0.122	3.162	88.38	-182.41	24.08	-51.45	19.71
10	70	0	30	15.75	2.80	5.62	2.23	0.581	0.103	-0.208	5.096	147.44	-147.44	15.60	-37.56	24.83
11	60	40	0	13.20	9.27	1.42	0.85	0.038	0.026	0.627	1.208	73.53	-157.10	51.63	-110.30	12.58
12	60	30	10	13.66	7.79	1.75	1.31	0.103	0.059	0.497	1.494	76.06	-162.50	43.37	-92.66	14.59
13	60	20	20	14.01	6.28	2.23	1.77	0.199	0.089	0.344	1.932	78.04	-166.73	34.97	-74.70	19.71
14	60	10	30	14.18	4.75	2.99	2.23	0.350	0.117	0.139	2.673	79.00	-155.50	26.43	-56.46	24.83
15	60	0	40	13.94	3.19	4.37	2.69	0.625	0.143	-0.204	4.164	126.96	-124.20	17.77	-41.30	29.96
Fabric	**50**	**50**	**0**	**11.24**	**11.24**	**1.00**	**0.85**	**0.031**	**0.031**	**0.868**	**0.868**	**62.58**	**-133.71**	**62.58**	**-133.71**	**12.58**
17	50	40	10	11.71	9.75	1.20	1.31	0.083	0.069	0.727	1.036	65.19	-139.28	54.29	-115.99	14.59
18	50	30	20	12.10	8.23	1.47	1.77	0.152	0.103	0.577	1.279	67.41	-144.02	45.83	-97.91	19.71
19	50	20	30	12.39	6.68	1.85	2.23	0.250	0.135	0.404	1.649	68.99	-146.62	37.22	-79.51	24.83
20	50	10	40	12.47	5.11	2.44	2.69	0.400	0.164	0.180	2.264	69.44	-131.76	28.47	-60.83	29.96
21	50	0	50	12.13	3.52	3.44	3.15	0.658	0.191	-0.180	3.461	108.22	-102.63	19.61	-43.75	35.08
22	**40**	**40**	**20**	**10.17**	**10.17**	**1.00**	**1.77**	**0.123**	**0.123**	**0.868**	**0.868**	**56.65**	**-121.03**	**56.65**	**-121.03**	**19.71**
23	40	30	30	10.52	8.61	1.22	2.23	0.195	0.159	0.694	1.075	58.57	-125.12	47.94	-102.43	24.83
24	40	20	40	10.73	7.02	1.53	2.69	0.294	0.192	0.499	1.389	59.77	-122.69	39.09	-83.51	29.96
25	40	10	50	10.73	5.41	1.98	3.15	0.442	0.223	0.250	1.908	59.76	-110.11	30.11	-64.32	35.08
26	40	0	60	10.30	3.77	2.73	3.61	0.683	0.250	-0.133	2.900	90.56	-83.96	21.02	-44.67	40.20
27	**30**	**30**	**40**	**8.90**	**8.90**	**1.00**	**2.69**	**0.233**	**0.233**	**0.868**	**0.868**	**49.56**	**-105.88**	**49.56**	**-105.88**	**29.96**
28	30	20	50	9.05	7.26	1.25	3.15	0.333	0.267	0.643	1.136	50.41	-100.50	40.42	-84.78	35.08
29	30	10	60	8.97	5.60	1.60	3.61	0.477	0.297	0.364	1.579	49.98	-89.91	31.16	-63.82	40.20
30	30	0	70	8.47	3.92	2.16	4.07	0.703	0.325	-0.056	2.424	73.60	-67.09	21.81	-43.73	45.32
Quasi	**20**	**20**	**60**	**7.35**	**7.35**	**1.00**	**3.61**	**0.366**	**0.366**	**0.868**	**0.868**	**40.93**	**-79.60**	**40.93**	**-79.60**	**40.20**
32	20	10	70	7.20	5.63	1.28	4.07	0.507	0.396	0.548	1.248	40.12	-70.76	31.36	-59.69	45.32
33	20	0	80	6.64	3.90	1.70	4.53	0.719	0.422	0.074	1.987	57.13	-51.38	21.71	-40.55	50.44
34	10	10	80	5.42	5.42	1.00	4.53	0.532	0.532	0.868	0.868	30.21	-52.38	30.21	-52.38	50.44
35	10	0	90	4.80	3.63	1.32	4.99	0.733	0.555	0.315	1.524	41.01	-36.49	20.24	-34.60	55.57
Shear	**0**	**0**	**100**	**2.97**	**2.97**	**1.00**	**5.45**	**0.744**	**0.744**	**0.868**	**0.868**	**25.16**	**-25.16**	**25.16**	**-25.16**	**60.69**

Based upon Hexcel AS4 PAN-based carbon fiber with Hexcel 3501-6 350°F epoxy   Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for Standard Modulus Carbon/Epoxy (V_f = 62%, Density = 0.056 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	νxz	νzx	νyz	νzy	αz μ in/in/F
Uni	**100**	**0**	**0**	**1.40**	**0.85**	**0.50**	**0.250**	**0.017**	**0.407**	**0.406**	**12.000**
2	90	10	0	1.55	0.82	0.54	0.317	0.026	0.400	0.184	15.016
3	90	0	10	1.47	0.83	0.52	0.184	0.014	0.395	0.306	13.529
4	80	20	0	1.59	0.78	0.57	0.339	0.032	0.393	0.117	15.773
5	80	10	10	1.57	0.80	0.55	0.278	0.025	0.387	0.157	15.364
6	80	0	20	1.52	0.82	0.54	0.149	0.013	0.381	0.245	14.395
7	70	30	0	1.61	0.75	0.61	0.352	0.037	0.386	0.085	16.087
8	70	20	10	1.60	0.76	0.59	0.313	0.032	0.379	0.104	15.924
9	70	10	20	1.59	0.78	0.57	0.250	0.025	0.372	0.136	15.622
10	70	0	30	1.55	0.80	0.55	0.128	0.013	0.366	0.202	14.952
11	60	40	0	1.62	0.71	0.64	0.362	0.044	0.379	0.066	16.227
12	60	30	10	1.62	0.73	0.62	0.333	0.039	0.370	0.077	16.162
13	60	20	20	1.61	0.75	0.61	0.292	0.034	0.362	0.093	16.043
14	60	10	30	1.60	0.76	0.59	0.229	0.026	0.355	0.119	15.819
15	60	0	40	1.57	0.78	0.57	0.115	0.013	0.348	0.171	15.340
Fabric	**50**	**50**	**0**	**1.62**	**0.68**	**0.68**	**0.371**	**0.054**	**0.371**	**0.054**	**16.268**
17	50	40	10	1.62	0.69	0.66	0.348	0.048	0.360	0.060	16.257
18	50	30	20	1.62	0.71	0.64	0.318	0.043	0.350	0.069	16.219
19	50	20	30	1.62	0.73	0.62	0.276	0.036	0.341	0.083	16.136
20	50	10	40	1.61	0.75	0.61	0.213	0.027	0.334	0.105	15.973
21	50	0	50	1.59	0.76	0.59	0.106	0.014	0.327	0.147	15.623
22	**40**	**40**	**20**	**1.62**	**0.68**	**0.68**	**0.336**	**0.054**	**0.336**	**0.054**	**16.268**
23	40	30	30	1.62	0.69	0.66	0.305	0.047	0.325	0.061	16.255
24	40	20	40	1.62	0.71	0.64	0.262	0.040	0.316	0.073	16.205
25	40	10	50	1.61	0.73	0.62	0.201	0.030	0.308	0.092	16.092
26	40	0	60	1.60	0.75	0.61	0.101	0.016	0.302	0.128	15.838
27	**30**	**30**	**40**	**1.62**	**0.68**	**0.68**	**0.294**	**0.054**	**0.294**	**0.054**	**16.268**
28	30	20	50	1.62	0.69	0.66	0.251	0.045	0.284	0.064	16.251
29	30	10	60	1.62	0.71	0.64	0.191	0.035	0.277	0.080	16.182
30	30	0	70	1.61	0.73	0.62	0.098	0.019	0.270	0.111	16.005
Quasi	**20**	**20**	**60**	**1.62**	**0.68**	**0.68**	**0.243**	**0.054**	**0.243**	**0.054**	**16.268**
32	20	10	70	1.62	0.69	0.66	0.184	0.042	0.235	0.068	16.243
33	20	0	80	1.62	0.71	0.64	0.097	0.024	0.229	0.095	16.133
34	10	10	80	1.62	0.68	0.68	0.179	0.054	0.179	0.054	16.268
35	10	0	90	1.62	0.69	0.66	0.097	0.033	0.175	0.078	16.225
Shear	**0**	**0**	**100**	**1.62**	**0.68**	**0.68**	**0.098**	**0.054**	**0.098**	**0.054**	**16.268**

Based upon Hexcel AS4 PAN-based carbon fiber with Hexcel 3501-6 350°F epoxy

2D (XY) Properties & Strengths for Intermediate Modulus Carbon/Epoxy
(V_f = 60%, Density = 0.056 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	νxy	νyx	αx μ in/in/F	αy μ in/in/F	+σx (ksi)	-σx (ksi)	+σy (ksi)	-σy (ksi)	τxy (ksi)
Uni	**100**	**0**	**0**	**31.49**	**1.00**	**31.49**	**0.57**	**0.300**	**0.010**	**0.000**	**18.720**	**330.02**	**-154.96**	**7.00**	**-24.41**	**8.50**
2	90	10	0	28.50	4.06	7.02	0.57	0.074	0.011	0.198	4.285	199.50	-140.25	28.40	-19.97	8.50
3	90	0	10	28.70	1.75	16.38	1.31	0.583	0.036	-0.149	10.212	270.30	-141.23	12.26	-17.88	12.92
4	80	20	0	25.45	7.11	3.58	0.57	0.042	0.012	0.298	2.256	178.16	-125.25	49.80	-35.01	8.50
5	80	10	10	26.03	4.81	5.42	1.31	0.215	0.040	0.153	3.434	182.19	-128.08	33.64	-23.65	12.92
6	80	0	20	25.80	2.46	10.50	2.06	0.693	0.066	-0.200	6.918	227.15	-126.96	17.20	-25.90	20.23
7	70	30	0	22.40	10.17	2.20	0.57	0.030	0.013	0.408	1.445	156.79	-110.22	71.20	-50.06	8.50
8	70	20	10	23.06	7.86	2.93	1.31	0.132	0.045	0.298	1.920	161.39	-113.46	55.00	-38.67	12.92
9	70	10	20	23.41	5.50	4.26	2.06	0.317	0.074	0.134	2.824	163.89	-115.22	38.50	-27.07	20.23
10	70	0	30	22.86	3.10	7.37	2.80	0.752	0.102	-0.220	5.164	194.57	-112.52	21.73	-34.02	27.53
11	60	40	0	19.34	13.23	1.46	0.57	0.023	0.016	0.547	1.009	135.40	-95.18	92.60	-65.10	8.50
12	60	30	10	20.04	10.91	1.84	1.31	0.095	0.052	0.443	1.251	140.25	-98.60	76.36	-53.68	12.92
13	60	20	20	20.55	8.54	2.41	2.06	0.205	0.085	0.318	1.641	143.88	-101.15	59.77	-42.02	20.23
14	60	10	30	20.71	6.13	3.38	2.80	0.394	0.116	0.136	2.359	144.99	-101.93	42.88	-30.14	27.53
15	60	0	40	19.92	3.67	5.42	3.54	0.789	0.145	-0.224	4.069	166.02	-98.00	25.71	-42.30	34.84
Fabric	**50**	**50**	**0**	**16.29**	**16.29**	**1.00**	**0.57**	**0.018**	**0.018**	**0.735**	**0.735**	**114.00**	**-80.14**	**114.00**	**-80.14**	**8.50**
17	50	40	10	17.00	13.96	1.22	1.31	0.074	0.061	0.623	0.871	119.00	-83.66	97.69	-68.68	12.92
18	50	30	20	17.59	11.57	1.52	2.06	0.152	0.100	0.502	1.074	123.15	-86.57	80.99	-56.94	20.23
19	50	20	30	17.98	9.13	1.97	2.80	0.267	0.136	0.359	1.400	125.83	-88.46	63.94	-44.95	27.53
20	50	10	40	17.95	6.66	2.70	3.54	0.454	0.168	0.158	1.986	125.66	-88.34	46.59	-32.75	34.84
21	50	0	50	16.96	4.14	4.10	4.28	0.813	0.198	-0.217	3.315	139.44	-83.45	28.97	-50.81	42.15
22	**40**	**40**	**20**	**14.59**	**14.59**	**1.00**	**2.06**	**0.121**	**0.121**	**0.735**	**0.735**	**102.14**	**-71.80**	**102.14**	**-71.80**	**20.23**
23	40	30	30	15.08	12.13	1.24	2.80	0.202	0.162	0.594	0.906	105.58	-74.22	84.88	-59.67	27.53
24	40	20	40	15.34	9.61	1.60	3.54	0.319	0.200	0.429	1.180	107.36	-75.47	67.27	-47.29	34.84
25	40	10	50	15.15	7.05	2.15	4.28	0.502	0.234	0.206	1.670	106.05	-74.55	49.38	-34.71	42.15
26	40	0	60	14.00	4.46	3.14	5.03	0.831	0.265	-0.197	2.756	113.96	-68.88	31.23	-52.58	49.46
27	**30**	**30**	**40**	**12.52**	**12.52**	**1.00**	**3.54**	**0.246**	**0.246**	**0.735**	**0.735**	**87.63**	**-61.60**	**87.63**	**-61.60**	**34.84**
28	30	20	50	12.65	9.91	1.28	4.28	0.363	0.284	0.543	0.966	88.55	-62.25	69.36	-48.76	42.15
29	30	10	60	12.32	7.26	1.70	5.03	0.542	0.319	0.289	1.383	86.22	-60.61	50.82	-35.73	49.46
30	30	0	70	11.03	4.58	2.41	5.77	0.845	0.351	-0.158	2.312	89.17	-54.30	32.05	-50.55	56.77
Quasi	**20**	**20**	**60**	**9.93**	**9.93**	**1.00**	**5.03**	**0.402**	**0.402**	**0.735**	**0.735**	**69.48**	**-48.84**	**69.48**	**-48.84**	**49.46**
32	20	10	70	9.46	7.17	1.32	5.77	0.575	0.436	0.439	1.092	66.23	-46.56	50.19	-35.28	56.77
33	20	0	80	8.07	4.39	1.84	6.51	0.856	0.465	-0.084	1.925	64.83	-39.70	30.72	-44.65	64.07
34	10	10	80	6.59	6.59	1.00	6.51	0.603	0.603	0.735	0.735	46.12	-32.42	46.12	-32.42	64.07
35	10	0	90	5.10	3.70	1.38	7.25	0.864	0.627	0.084	1.519	40.80	-25.10	25.91	-33.91	71.38
Shear	**0**	**0**	**100**	**2.13**	**2.13**	**1.00**	**8.00**	**0.871**	**0.871**	**0.735**	**0.735**	**17.00**	**-17.00**	**17.00**	**-17.00**	**78.69**

Based upon Toray M40J PAN-based fiber with Toray 3631 350°F epoxy

Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for Intermediate Modulus Carbon /Epoxy
(V_f = 60%, Density = 0.056 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	ν_{xz}	ν_{zx}	ν_{yz}	ν_{zy}	α_z μ in/in/F
Uni	**100**	**0**	**0**	**1.00**	**0.57**	**0.39**	**0.300**	**0.010**	**0.419**	**0.419**	**18.720**
2	90	10	0	1.15	0.55	0.40	0.395	0.016	0.419	0.119	24.738
3	90	0	10	1.09	0.56	0.39	0.180	0.007	0.408	0.253	22.379
4	80	20	0	1.18	0.53	0.42	0.408	0.019	0.419	0.069	25.554
5	80	10	10	1.16	0.54	0.41	0.335	0.015	0.407	0.098	25.117
6	80	0	20	1.12	0.55	0.40	0.133	0.006	0.395	0.181	23.793
7	70	30	0	1.18	0.51	0.44	0.413	0.022	0.418	0.049	25.849
8	70	20	10	1.18	0.52	0.43	0.370	0.019	0.405	0.061	25.695
9	70	10	20	1.17	0.53	0.42	0.292	0.015	0.392	0.083	25.383
10	70	0	30	1.15	0.54	0.41	0.108	0.005	0.380	0.140	24.543
11	60	40	0	1.19	0.50	0.46	0.416	0.026	0.418	0.038	25.975
12	60	30	10	1.19	0.51	0.45	0.385	0.023	0.402	0.044	25.917
13	60	20	20	1.18	0.51	0.44	0.339	0.019	0.388	0.054	25.805
14	60	10	30	1.18	0.52	0.43	0.259	0.015	0.374	0.072	25.578
15	60	0	40	1.16	0.53	0.42	0.092	0.005	0.362	0.114	25.008
Fabric	**50**	**50**	**0**	**1.19**	**0.48**	**0.48**	**0.417**	**0.030**	**0.417**	**0.030**	**26.011**
17	50	40	10	1.19	0.49	0.47	0.393	0.028	0.399	0.034	26.001
18	50	30	20	1.19	0.50	0.46	0.361	0.024	0.382	0.039	25.967
19	50	20	30	1.19	0.51	0.45	0.312	0.021	0.367	0.048	25.889
20	50	10	40	1.18	0.51	0.44	0.233	0.015	0.352	0.063	25.726
21	50	0	50	1.17	0.52	0.43	0.081	0.006	0.339	0.096	25.323
22	**40**	**40**	**20**	**1.19**	**0.48**	**0.48**	**0.374**	**0.030**	**0.374**	**0.030**	**26.011**
23	40	30	30	1.19	0.49	0.47	0.339	0.027	0.356	0.035	25.999
24	40	20	40	1.19	0.50	0.46	0.290	0.022	0.340	0.042	25.953
25	40	10	50	1.18	0.51	0.45	0.212	0.017	0.325	0.055	25.840
26	40	0	60	1.18	0.51	0.44	0.073	0.006	0.311	0.082	25.551
27	**30**	**30**	**40**	**1.19**	**0.48**	**0.48**	**0.321**	**0.030**	**0.321**	**0.030**	**26.011**
28	30	20	50	1.19	0.49	0.47	0.271	0.025	0.304	0.036	25.995
29	30	10	60	1.19	0.50	0.46	0.195	0.019	0.289	0.047	25.926
30	30	0	70	1.18	0.51	0.45	0.067	0.007	0.275	0.071	25.723
Quasi	**20**	**20**	**60**	**1.19**	**0.48**	**0.48**	**0.254**	**0.030**	**0.254**	**0.030**	**26.011**
32	20	10	70	1.19	0.49	0.47	0.181	0.023	0.240	0.040	25.986
33	20	0	80	1.18	0.50	0.46	0.062	0.009	0.227	0.061	25.855
34	10	10	80	1.19	0.48	0.48	0.169	0.030	0.169	0.030	26.011
35	10	0	90	1.19	0.49	0.47	0.058	0.014	0.158	0.051	25.955
Shear	**0**	**0**	**100**	**1.19**	**0.48**	**0.48**	**0.055**	**0.030**	**0.055**	**0.030**	**26.011**

Based upon Toray M40J PAN-based fiber with Toray 3631 350°F epoxy

2D (XY) Properties & Strengths for High Modulus Carbon/Epoxy
(V_f = 60%, Density = 0.064 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	ν_{xy}	ν_{yx}	α_x μ in/in/F	α_y μ in/in/F	$+\sigma_x$ (ksi)	$-\sigma_x$ (ksi)	$+\sigma_y$ (ksi)	$-\sigma_y$ (ksi)	τ_{xy} (ksi)
Uni	**100**	**0**	**0**	**54.85**	**0.80**	**68.22**	**0.61**	**0.316**	**0.005**	**-0.599**	**17.130**	**221.98**	**-62.04**	**5.50**	**-26.56**	**11.00**
2	90	10	0	49.51	6.22	7.96	0.61	0.041	0.005	-0.499	1.536	200.36	-55.99	25.16	-7.03	11.00
3	90	0	10	49.77	2.14	23.23	1.93	0.719	0.031	-0.697	5.764	201.43	-56.29	14.66	-5.00	4.35
4	80	20	0	44.10	11.63	3.79	0.61	0.022	0.006	-0.458	0.458	178.47	-49.88	47.06	-13.15	11.00
5	80	10	10	45.17	7.55	5.98	1.93	0.207	0.035	-0.525	1.071	182.78	-51.08	30.55	-8.54	4.35
6	80	0	20	44.54	3.40	13.10	3.25	0.809	0.062	-0.717	3.214	180.23	-50.37	23.25	-8.19	7.34
7	70	30	0	38.69	17.04	2.27	0.61	0.015	0.007	-0.411	0.064	156.57	-43.76	68.97	-19.27	11.00
8	70	20	10	39.89	12.95	3.08	1.93	0.121	0.039	-0.461	0.294	161.43	-45.11	52.43	-14.65	4.35
9	70	10	20	40.53	8.79	4.61	3.25	0.322	0.070	-0.537	0.752	142.37	-45.84	35.56	-9.94	7.34
10	70	0	30	39.27	4.55	8.63	4.57	0.849	0.098	-0.724	2.088	158.93	-44.42	31.12	-11.41	10.33
11	60	40	0	33.28	22.45	1.48	0.61	0.011	0.008	-0.350	-0.140	134.67	-37.64	90.87	-25.39	11.00
12	60	30	10	34.53	18.36	1.88	1.93	0.085	0.045	-0.396	-0.027	139.75	-39.06	74.29	-20.76	4.35
13	60	20	20	35.47	14.17	2.50	3.25	0.201	0.080	-0.453	0.160	143.55	-40.12	57.35	-16.03	7.34
14	60	10	30	35.73	9.90	3.61	4.57	0.406	0.113	-0.539	0.517	99.47	-40.41	40.07	-11.20	10.33
15	60	0	40	34.00	5.56	6.11	5.89	0.872	0.143	-0.725	1.451	137.60	-38.45	38.04	-14.67	13.31
Fabric	**50**	**50**	**0**	**27.87**	**27.87**	**1.00**	**0.61**	**0.009**	**0.009**	**-0.265**	**-0.265**	**112.77**	**-31.52**	**112.77**	**-31.52**	**11.00**
17	50	40	10	29.15	23.76	1.23	1.93	0.066	0.054	-0.316	-0.203	117.97	-32.97	96.14	-26.87	4.35
18	50	30	20	30.22	19.54	1.55	3.25	0.146	0.094	-0.370	-0.109	122.29	-34.18	79.08	-22.10	7.34
19	50	20	30	30.90	15.23	2.03	4.57	0.267	0.132	-0.436	0.045	125.06	-34.95	61.65	-17.23	10.33
20	50	10	40	30.81	10.85	2.84	5.89	0.471	0.166	-0.531	0.334	74.04	-34.84	43.89	-12.27	13.31
21	50	0	50	28.72	6.39	4.50	7.21	0.886	0.197	-0.722	1.040	116.24	-32.49	36.66	-17.99	16.30
22	**40**	**40**	**20**	**24.90**	**24.90**	**1.00**	**3.25**	**0.115**	**0.115**	**-0.265**	**-0.265**	**100.75**	**-28.16**	**100.75**	**-28.16**	**7.34**
23	40	30	30	25.78	20.53	1.26	4.57	0.199	0.158	-0.330	-0.186	104.31	-29.15	83.10	-23.22	10.33
24	40	20	40	26.22	16.08	1.63	5.89	0.322	0.198	-0.405	-0.058	92.00	-29.65	65.08	-18.19	13.31
25	40	10	50	25.81	11.55	2.23	7.21	0.521	0.233	-0.511	0.181	55.99	-29.19	46.74	-13.06	16.30
26	40	0	60	23.44	6.95	3.37	8.53	0.896	0.266	-0.715	0.749	94.88	-26.52	29.59	-21.41	19.29
27	**30**	**30**	**40**	**21.23**	**21.23**	**1.00**	**5.89**	**0.245**	**0.245**	**-0.265**	**-0.265**	**85.92**	**-24.01**	**85.92**	**-24.01**	**13.31**
28	30	20	50	21.44	16.60	1.29	7.21	0.369	0.286	-0.354	-0.157	65.66	-24.25	65.66	-18.78	16.30
29	30	10	60	20.76	11.90	1.74	8.53	0.562	0.322	-0.474	0.045	41.74	-23.48	41.74	-13.46	19.29
30	30	0	70	18.16	7.14	2.55	9.85	0.904	0.355	-0.703	0.528	73.51	-20.54	22.73	-25.03	22.27
Quasi	**20**	**20**	**60**	**16.60**	**16.60**	**1.00**	**8.53**	**0.410**	**0.410**	**-0.265**	**-0.265**	**45.80**	**-18.77**	**45.80**	**-18.77**	**19.29**
32	20	10	70	15.67	11.69	1.34	9.85	0.596	0.445	-0.407	-0.093	29.71	-17.72	29.71	-13.23	22.27
33	20	0	80	12.88	6.75	1.91	11.17	0.909	0.476	-0.677	0.344	52.14	-14.57	16.02	-29.12	25.26
34	10	10	80	10.55	10.55	1.00	11.17	0.625	0.625	-0.265	-0.265	19.09	-11.93	19.09	-11.93	25.26
35	10	0	90	7.60	5.40	1.41	12.49	0.914	0.649	-0.615	0.160	30.77	-8.60	9.41	-33.67	28.24
Shear	**0**	**0**	**100**	**2.32**	**2.32**	**1.00**	**13.81**	**0.917**	**0.917**	**-0.265**	**-0.265**	**22.00**	**-22.00**	**22.00**	**-22.00**	**31.23**

Based upon Mitsubishi K63712 Pitch-based fiber with Mitsubishi AY33 250°F epoxy   Ultimate strengths may be substantially higher

Ability COMPOSITES

Through-The-Thickness (Z) Properties for High Modulus Carbon /Epoxy
(V_f = 60%, Density = 0.064 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	ν_{xz}	ν_{zx}	ν_{yz}	ν_{zy}	α_z μ in/in/F
Uni	**100**	**0**	**0**	**0.80**	**0.61**	**0.37**	**0.316**	**0.005**	**0.420**	**0.420**	**17.130**
2	90	10	0	0.95	0.58	0.39	0.429	0.008	0.423	0.065	23.663
3	90	0	10	0.91	0.59	0.38	0.144	0.003	0.410	0.173	21.964
4	80	20	0	0.96	0.56	0.41	0.435	0.009	0.425	0.035	24.101
5	80	10	10	0.95	0.57	0.40	0.357	0.008	0.411	0.052	23.870
6	80	0	20	0.93	0.58	0.39	0.103	0.002	0.397	0.109	23.047
7	70	30	0	0.96	0.53	0.44	0.435	0.011	0.427	0.024	24.247
8	70	20	10	0.96	0.55	0.43	0.391	0.009	0.412	0.031	24.171
9	70	10	20	0.96	0.56	0.41	0.306	0.007	0.397	0.043	24.010
10	70	0	30	0.95	0.57	0.40	0.083	0.002	0.382	0.080	23.525
11	60	40	0	0.97	0.51	0.46	0.434	0.013	0.430	0.018	24.307
12	60	30	10	0.97	0.52	0.45	0.403	0.011	0.412	0.022	24.279
13	60	20	20	0.96	0.53	0.44	0.355	0.010	0.395	0.027	24.224
14	60	10	30	0.96	0.55	0.43	0.268	0.007	0.379	0.037	24.109
15	60	0	40	0.95	0.56	0.41	0.071	0.002	0.364	0.062	23.794
Fabric	**50**	**50**	**0**	**0.97**	**0.49**	**0.49**	**0.432**	**0.015**	**0.432**	**0.015**	**24.324**
17	50	40	10	0.97	0.50	0.47	0.408	0.014	0.411	0.017	24.319
18	50	30	20	0.97	0.51	0.46	0.375	0.012	0.392	0.019	24.302
19	50	20	30	0.97	0.52	0.45	0.325	0.010	0.374	0.024	24.265
20	50	10	40	0.96	0.53	0.44	0.239	0.007	0.357	0.032	24.183
21	50	0	50	0.96	0.55	0.43	0.062	0.002	0.342	0.051	23.966
22	**40**	**40**	**20**	**0.97**	**0.49**	**0.49**	**0.386**	**0.015**	**0.386**	**0.015**	**24.324**
23	40	30	30	0.97	0.50	0.47	0.351	0.013	0.365	0.017	24.318
24	40	20	40	0.97	0.51	0.46	0.299	0.011	0.346	0.021	24.295
25	40	10	50	0.96	0.52	0.45	0.215	0.008	0.329	0.027	24.239
26	40	0	60	0.96	0.53	0.44	0.056	0.002	0.313	0.043	24.086
27	**30**	**30**	**40**	**0.97**	**0.49**	**0.49**	**0.329**	**0.015**	**0.329**	**0.015**	**24.324**
28	30	20	50	0.97	0.50	0.47	0.277	0.012	0.309	0.018	24.316
29	30	10	60	0.97	0.51	0.46	0.195	0.009	0.292	0.024	24.282
30	30	0	70	0.96	0.52	0.45	0.050	0.003	0.276	0.037	24.174
Quasi	**20**	**20**	**60**	**0.97**	**0.49**	**0.49**	**0.257**	**0.015**	**0.257**	**0.015**	**24.324**
32	20	10	70	0.97	0.50	0.47	0.178	0.011	0.240	0.020	24.311
33	20	0	80	0.96	0.51	0.46	0.045	0.003	0.224	0.032	24.241
34	10	10	80	0.97	0.49	0.49	0.163	0.015	0.163	0.015	24.324
35	10	0	90	0.97	0.50	0.47	0.040	0.005	0.151	0.027	24.292
Shear	**0**	**0**	**100**	**0.97**	**0.49**	**0.49**	**0.036**	**0.015**	**0.036**	**0.015**	**24.324**

Based upon Mitsubishi K63712 Pitch-based fiber with Mitsubishi AY33 250°F epoxy

2D (XY) Properties & Strengths for Very-High Modulus Carbon/Epoxy
(V_f = 60%, Density = 0.065 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	νxy	νyx	αx μ in/in/F	αy μ in/in/F	+σx (ksi)	-σx (ksi)	+σy (ksi)	-σy (ksi)	τxy (ksi)
Uni	**100**	**0**	**0**	**66.25**	**0.87**	**76.45**	**0.72**	**0.316**	**0.004**	**-0.655**	**17.126**	**324.00**	**-58.20**	**3.93**	**-26.20**	**9.72**
2	90	10	0	59.78	7.41	8.06	0.72	0.037	0.005	-0.564	1.280	271.14	-52.52	33.62	-6.51	9.72
3	90	0	10	60.10	2.49	24.14	2.31	0.734	0.030	-0.747	5.264	293.91	-52.79	11.29	-4.51	4.06
4	80	20	0	53.24	13.96	3.81	0.72	0.020	0.005	-0.528	0.297	241.47	-46.77	63.32	-12.26	9.72
5	80	10	10	54.54	9.03	6.04	2.31	0.206	0.034	-0.588	0.854	233.12	-47.91	40.96	-7.93	4.06
6	80	0	20	53.76	4.01	13.40	3.91	0.820	0.061	-0.763	2.836	262.92	-47.23	18.20	-7.51	6.86
7	70	30	0	46.69	20.51	2.28	0.72	0.013	0.006	-0.486	-0.059	211.78	-41.02	93.01	-18.02	9.72
8	70	20	10	48.15	15.57	3.09	2.31	0.119	0.039	-0.530	0.148	218.40	-42.30	70.61	-13.68	4.06
9	70	10	20	48.94	10.53	4.65	3.91	0.322	0.069	-0.599	0.564	133.72	-42.99	47.77	-9.25	6.86
10	70	0	30	47.40	5.41	8.76	5.50	0.857	0.098	-0.769	1.788	231.81	-41.64	24.54	-10.53	9.67
11	60	40	0	40.15	27.05	1.48	0.72	0.010	0.007	-0.431	-0.243	182.09	-35.27	122.70	-23.77	9.72
12	60	30	10	41.67	22.10	1.89	2.31	0.084	0.045	-0.473	-0.141	189.00	-36.61	100.25	-19.42	4.06
13	60	20	20	42.81	17.04	2.51	3.91	0.200	0.080	-0.524	0.027	188.08	-37.61	77.30	-14.97	6.86
14	60	10	30	43.13	11.88	3.63	5.50	0.406	0.112	-0.601	0.351	93.27	-37.89	53.91	-10.44	9.67
15	60	0	40	41.03	6.64	6.18	7.10	0.877	0.142	-0.769	1.202	200.65	-36.04	30.11	-13.59	12.47
Fabric	**50**	**50**	**0**	**33.60**	**33.60**	**1.00**	**0.72**	**0.008**	**0.008**	**-0.355**	**-0.355**	**152.40**	**-29.52**	**152.40**	**-29.52**	**9.72**
17	50	40	10	35.16	28.63	1.23	2.31	0.065	0.053	-0.401	-0.300	159.47	-30.89	129.88	-25.16	4.06
18	50	30	20	36.46	23.54	1.55	3.91	0.145	0.094	-0.450	-0.215	165.36	-32.03	106.78	-20.68	6.86
19	50	20	30	37.29	18.34	2.03	5.50	0.266	0.131	-0.509	-0.076	123.05	-32.76	83.16	-16.11	9.67
20	50	10	40	37.18	13.03	2.85	7.10	0.471	0.165	-0.594	0.184	69.38	-32.67	59.11	-11.45	12.47
21	50	0	50	34.65	7.64	4.53	8.69	0.890	0.196	-0.767	0.826	169.47	-30.44	34.19	-16.71	15.27
22	**40**	**40**	**20**	**30.02**	**30.02**	**1.00**	**3.91**	**0.114**	**0.114**	**-0.355**	**-0.355**	**136.15**	**-26.37**	**136.15**	**-26.37**	**6.86**
23	40	30	30	31.09	24.75	1.26	5.50	0.198	0.158	-0.413	-0.284	137.93	-27.31	112.25	-21.74	9.67
24	40	20	40	31.63	19.37	1.63	7.10	0.322	0.197	-0.481	-0.168	86.36	-27.79	86.36	-17.01	12.47
25	40	10	50	31.15	13.89	2.24	8.69	0.522	0.233	-0.576	0.047	52.45	-27.36	52.45	-12.20	15.27
26	40	0	60	28.27	8.33	3.39	10.29	0.900	0.265	-0.760	0.561	138.28	-24.84	27.61	-19.92	18.07
27	**30**	**30**	**40**	**25.60**	**25.60**	**1.00**	**7.10**	**0.244**	**0.244**	**-0.355**	**-0.355**	**92.02**	**-22.49**	**92.02**	**-22.49**	**12.47**
28	30	20	50	25.86	20.00	1.29	8.69	0.369	0.285	-0.435	-0.258	61.58	-22.72	61.58	-17.57	15.27
29	30	10	60	25.04	14.32	1.75	10.29	0.563	0.322	-0.543	-0.076	39.09	-22.00	39.09	-12.58	18.07
30	30	0	70	21.89	8.56	2.56	11.88	0.906	0.355	-0.749	0.361	107.08	-19.23	21.22	-23.31	20.87
Quasi	**20**	**20**	**60**	**20.00**	**20.00**	**1.00**	**10.29**	**0.409**	**0.409**	**-0.355**	**-0.355**	**42.91**	**-17.57**	**42.91**	**-17.57**	**18.07**
32	20	10	70	18.89	14.08	1.34	11.88	0.597	0.445	-0.483	-0.200	27.81	-16.59	27.81	-12.37	20.87
33	20	0	80	15.51	8.10	1.92	13.47	0.911	0.476	-0.727	0.195	75.88	-13.63	14.96	-27.14	23.67
34	10	10	80	12.70	12.70	1.00	13.47	0.625	0.625	-0.355	-0.355	17.84	-11.16	17.84	-11.16	23.67
35	10	0	90	9.13	6.48	1.41	15.07	0.915	0.649	-0.671	0.029	44.67	-8.02	8.77	-32.47	26.48
Shear	**0**	**0**	**100**	**2.75**	**2.75**	**1.00**	**16.66**	**0.919**	**0.919**	**-0.355**	**-0.355**	**19.45**	**-19.45**	**19.45**	**-19.45**	**29.28**

Based upon Mitsubishi K1392U Pitch-based fiber with Mitsubishi AY33 250°F epoxy   Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for Very-High Modulus Carbon /Epoxy (V_f = 60%, Density = 0.065 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	νxz	νzx	νyz	νzy	αz μ in/in/F
Uni	**100**	**0**	**0**	0.87	0.72	0.37	0.316	0.004	0.420	0.420	17.126
2	90	10	0	1.03	0.68	0.40	0.431	0.007	0.423	0.059	23.770
3	90	0	10	0.98	0.70	0.38	0.137	0.002	0.410	0.162	22.167
4	80	20	0	1.04	0.65	0.44	0.436	0.008	0.425	0.032	24.170
5	80	10	10	1.03	0.66	0.42	0.358	0.007	0.411	0.047	23.960
6	80	0	20	1.01	0.68	0.40	0.098	0.002	0.398	0.100	23.198
7	70	30	0	1.04	0.61	0.47	0.436	0.010	0.428	0.022	24.302
8	70	20	10	1.04	0.63	0.45	0.391	0.008	0.412	0.028	24.233
9	70	10	20	1.04	0.65	0.44	0.306	0.006	0.397	0.039	24.087
10	70	0	30	1.02	0.66	0.42	0.080	0.002	0.383	0.072	23.642
11	60	40	0	1.04	0.58	0.51	0.434	0.011	0.430	0.017	24.356
12	60	30	10	1.04	0.59	0.49	0.404	0.010	0.412	0.019	24.331
13	60	20	20	1.04	0.61	0.47	0.355	0.009	0.395	0.024	24.282
14	60	10	30	1.04	0.63	0.45	0.268	0.006	0.379	0.033	24.177
15	60	0	40	1.03	0.65	0.44	0.069	0.002	0.365	0.057	23.889
Fabric	**50**	**50**	**0**	1.04	0.54	0.54	0.432	0.013	0.432	0.013	24.371
17	50	40	10	1.04	0.56	0.52	0.409	0.012	0.411	0.015	24.367
18	50	30	20	1.04	0.58	0.51	0.376	0.011	0.392	0.017	24.352
19	50	20	30	1.04	0.59	0.49	0.325	0.009	0.374	0.021	24.318
20	50	10	40	1.04	0.61	0.47	0.239	0.007	0.358	0.029	24.245
21	50	0	50	1.03	0.63	0.45	0.061	0.002	0.342	0.046	24.047
22	**40**	**40**	**20**	1.04	0.54	0.54	0.386	0.013	0.386	0.013	24.371
23	40	30	30	1.04	0.56	0.52	0.351	0.012	0.366	0.015	24.366
24	40	20	40	1.04	0.58	0.51	0.299	0.010	0.347	0.019	24.346
25	40	10	50	1.04	0.59	0.49	0.215	0.007	0.329	0.025	24.295
26	40	0	60	1.04	0.61	0.47	0.054	0.002	0.313	0.039	24.156
27	**30**	**30**	**40**	1.04	0.54	0.54	0.329	0.013	0.329	0.013	24.371
28	30	20	50	1.04	0.56	0.52	0.277	0.011	0.310	0.016	24.364
29	30	10	60	1.04	0.58	0.51	0.195	0.008	0.292	0.021	24.333
30	30	0	70	1.04	0.59	0.49	0.049	0.002	0.276	0.033	24.236
Quasi	**20**	**20**	**60**	1.04	0.54	0.54	0.257	0.013	0.257	0.013	24.371
32	20	10	70	1.04	0.56	0.52	0.178	0.010	0.240	0.018	24.360
33	20	0	80	1.04	0.58	0.51	0.044	0.003	0.224	0.029	24.296
34	10	10	80	1.04	0.54	0.54	0.163	0.013	0.163	0.013	24.371
35	10	0	90	1.04	0.56	0.52	0.039	0.005	0.151	0.024	24.343
Shear	**0**	**0**	**100**	1.04	0.54	0.54	0.035	0.013	0.035	0.013	24.371

Based upon Mitsubishi K1392U Pitch-based fiber with Mitsubishi AY33 250°F epoxy

2D (XY) Properties & Strengths for Ultra-High Modulus Carbon/Epoxy

(V_f = 60%, Density = 0.066 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ex (Msi)	Ey (Msi)	Ex/Ey	Gxy (Msi)	νxy	νyx	αx μ in/in/F	αy μ in/in/F	+σx (ksi)	-σx (ksi)	+σy (ksi)	-σy (ksi)	τxy (ksi)
Uni	**100**	**0**	**0**	**81.25**	**0.77**	**105.4**	**0.46**	**0.316**	**0.003**	**-0.648**	**17.147**	**330.00**	**-54.00**	**4.01**	**-26.76**	**7.29**
2	90	10	0	73.26	8.83	8.30	0.46	0.028	0.003	-0.581	0.800	297.57	-48.69	35.85	-5.87	7.29
3	90	0	10	73.52	2.74	26.84	2.45	0.798	0.030	-0.726	4.144	298.60	-48.86	14.26	-3.75	3.26
4	80	20	0	65.21	16.88	3.86	0.46	0.014	0.004	-0.555	0.053	264.86	-43.34	68.57	-11.22	7.29
5	80	10	10	66.79	10.79	6.19	2.45	0.206	0.033	-0.600	0.477	215.38	-44.39	43.81	-7.17	3.26
6	80	0	20	65.58	4.58	14.32	4.45	0.875	0.061	-0.738	2.076	266.36	-43.59	23.84	-6.48	5.91
7	70	30	0	57.16	24.94	2.29	0.46	0.010	0.004	-0.525	-0.211	232.15	-37.99	101.28	-16.57	7.29
8	70	20	10	58.93	18.83	3.13	2.45	0.118	0.038	-0.557	-0.057	239.34	-39.17	76.49	-12.52	3.26
9	70	10	20	59.84	12.60	4.75	4.45	0.328	0.069	-0.609	0.259	121.15	-39.77	51.18	-8.38	5.91
10	70	0	30	57.62	6.26	9.21	6.44	0.906	0.098	-0.742	1.231	234.02	-38.29	32.58	-9.23	8.56
11	60	40	0	49.10	32.99	1.49	0.46	0.007	0.005	-0.484	-0.347	199.43	-32.63	134.00	-21.93	7.29
12	60	30	10	50.95	26.87	1.90	2.45	0.083	0.044	-0.515	-0.272	206.95	-33.86	109.15	-17.86	3.26
13	60	20	20	52.32	20.61	2.54	4.45	0.202	0.080	-0.553	-0.146	172.09	-34.77	83.72	-13.70	5.91
14	60	10	30	52.61	14.22	3.70	6.44	0.417	0.113	-0.611	0.100	83.81	-34.96	57.78	-9.45	8.56
15	60	0	40	49.65	7.72	6.43	8.44	0.923	0.144	-0.743	0.771	201.65	-33.00	35.74	-11.99	11.21
Fabric	**50**	**50**	**0**	**41.05**	**41.05**	**1.00**	**0.46**	**0.006**	**0.006**	**-0.429**	**-0.429**	**166.72**	**-27.28**	**166.72**	**-27.28**	**7.29**
17	50	40	10	42.94	34.91	1.23	2.45	0.064	0.052	-0.463	-0.388	174.40	-28.54	141.79	-23.20	3.26
18	50	30	20	44.50	28.61	1.56	4.45	0.146	0.094	-0.499	-0.326	180.73	-29.57	116.19	-19.01	5.91
19	50	20	30	45.46	22.16	2.05	6.44	0.271	0.132	-0.542	-0.222	111.52	-30.21	90.01	-14.73	8.56
20	50	10	40	45.20	15.59	2.90	8.44	0.485	0.167	-0.607	-0.024	61.97	-30.04	61.97	-10.36	11.21
21	50	0	50	41.67	8.90	4.68	10.43	0.934	0.199	-0.743	0.481	169.27	-27.70	29.66	-14.78	13.86
22	**40**	**40**	**20**	**36.58**	**36.58**	**1.00**	**4.45**	**0.114**	**0.114**	**-0.429**	**-0.429**	**148.56**	**-24.31**	**148.56**	**-24.31**	**5.91**
23	40	30	30	37.84	30.05	1.26	6.44	0.201	0.159	-0.472	-0.377	125.37	-25.15	122.04	-19.97	8.56
24	40	20	40	38.42	23.37	1.64	8.44	0.329	0.200	-0.522	-0.290	77.71	-25.54	77.71	-15.53	11.21
25	40	10	50	37.67	16.58	2.27	10.43	0.538	0.237	-0.595	-0.127	46.54	-25.03	46.54	-11.02	13.86
26	40	0	60	33.70	9.67	3.48	12.42	0.941	0.270	-0.740	0.281	136.88	-22.40	23.79	-17.62	16.52
27	**30**	**30**	**40**	**31.03**	**31.03**	**1.00**	**8.44**	**0.249**	**0.249**	**-0.429**	**-0.429**	**82.95**	**-20.62**	**82.95**	**-20.62**	**11.21**
28	30	20	50	31.25	24.08	1.30	10.43	0.378	0.291	-0.489	-0.357	54.99	-20.77	54.99	-16.00	13.86
29	30	10	60	30.05	17.01	1.77	12.42	0.581	0.329	-0.571	-0.218	34.39	-19.97	34.39	-11.31	16.52
30	30	0	70	25.72	9.85	2.61	14.42	0.947	0.363	-0.736	0.132	104.48	-17.10	18.06	-20.55	19.17
Quasi	**20**	**20**	**60**	**23.96**	**23.96**	**1.00**	**12.42**	**0.420**	**0.420**	**-0.429**	**-0.429**	**37.92**	**-15.92**	**37.92**	**-15.92**	**16.52**
32	20	10	70	22.37	16.58	1.35	14.42	0.616	0.457	-0.527	-0.310	24.13	-14.87	24.13	-11.02	19.17
33	20	0	80	17.75	9.12	1.95	16.41	0.951	0.489	-0.726	0.012	72.09	-11.80	12.41	-23.71	21.82
34	10	10	80	14.64	14.64	1.00	16.41	0.646	0.646	-0.429	-0.429	15.07	-9.73	15.07	-9.73	21.82
35	10	0	90	9.77	6.87	1.42	18.41	0.954	0.671	-0.699	-0.100	39.69	-6.49	6.81	-27.73	24.47
Shear	**0**	**0**	**100**	**1.79**	**1.79**	**1.00**	**20.40**	**0.957**	**0.957**	**-0.429**	**-0.429**	**14.58**	**-14.58**	**14.58**	**-14.58**	**27.12**

Based upon Mitsubishi K13C2U Pitch-based fiber with Fiberite 934 350°F epoxy   Ultimate strengths may be substantially higher

Through-The-Thickness (Z) Properties for Ultra-High Modulus Carbon /Epoxy
(V_f = 60%, Density = 0.066 lb./in^3)

Layup	%+-0	%+-90	%+-45	Ez (Msi)	Gxz (Msi)	Gyz (Msi)	νxz	νzx	νyz	νzy	αz μ in/in/F
Uni	**100**	**0**	**0**	**0.77**	**0.46**	**0.37**	**0.316**	**0.003**	**0.421**	**0.421**	**17.147**
2	90	10	0	0.92	0.45	0.37	0.435	0.005	0.423	0.044	24.014
3	90	0	10	0.89	0.45	0.37	0.110	0.001	0.410	0.133	22.665
4	80	20	0	0.93	0.44	0.38	0.438	0.006	0.426	0.023	24.318
5	80	10	10	0.92	0.44	0.38	0.357	0.005	0.411	0.035	24.158
6	80	0	20	0.91	0.45	0.37	0.075	0.001	0.398	0.079	23.542
7	70	30	0	0.93	0.43	0.39	0.437	0.007	0.428	0.016	24.417
8	70	20	10	0.93	0.44	0.39	0.392	0.006	0.412	0.020	24.365
9	70	10	20	0.93	0.44	0.38	0.304	0.005	0.397	0.029	24.254
10	70	0	30	0.92	0.44	0.38	0.059	0.001	0.382	0.056	23.900
11	60	40	0	0.93	0.42	0.40	0.435	0.008	0.431	0.012	24.457
12	60	30	10	0.93	0.43	0.40	0.404	0.007	0.412	0.014	24.438
13	60	20	20	0.93	0.43	0.39	0.354	0.006	0.395	0.018	24.401
14	60	10	30	0.93	0.44	0.39	0.264	0.005	0.379	0.025	24.322
15	60	0	40	0.92	0.44	0.38	0.049	0.001	0.364	0.043	24.094
Fabric	**50**	**50**	**0**	**0.93**	**0.41**	**0.41**	**0.433**	**0.010**	**0.433**	**0.010**	**24.468**
17	50	40	10	0.93	0.42	0.41	0.409	0.009	0.412	0.011	24.465
18	50	30	20	0.93	0.42	0.40	0.375	0.008	0.392	0.013	24.454
19	50	20	30	0.93	0.43	0.40	0.323	0.007	0.374	0.016	24.429
20	50	10	40	0.93	0.43	0.39	0.233	0.005	0.357	0.021	24.372
21	50	0	50	0.92	0.44	0.39	0.042	0.001	0.341	0.035	24.216
22	**40**	**40**	**20**	**0.93**	**0.41**	**0.41**	**0.386**	**0.010**	**0.386**	**0.010**	**24.468**
23	40	30	30	0.93	0.42	0.41	0.350	0.009	0.365	0.011	24.464
24	40	20	40	0.93	0.42	0.40	0.296	0.007	0.345	0.014	24.449
25	40	10	50	0.93	0.43	0.40	0.208	0.005	0.328	0.018	24.410
26	40	0	60	0.93	0.43	0.39	0.036	0.001	0.311	0.030	24.300
27	**30**	**30**	**40**	**0.93**	**0.41**	**0.41**	**0.327**	**0.010**	**0.327**	**0.010**	**24.468**
28	30	20	50	0.93	0.42	0.41	0.273	0.008	0.307	0.012	24.463
29	30	10	60	0.93	0.42	0.40	0.187	0.006	0.289	0.016	24.439
30	30	0	70	0.93	0.43	0.40	0.031	0.001	0.272	0.026	24.361
Quasi	**20**	**20**	**60**	**0.93**	**0.41**	**0.41**	**0.253**	**0.010**	**0.253**	**0.010**	**24.468**
32	20	10	70	0.93	0.42	0.41	0.170	0.007	0.235	0.013	24.459
33	20	0	80	0.93	0.42	0.40	0.027	0.001	0.219	0.022	24.408
34	10	10	80	0.93	0.41	0.41	0.154	0.010	0.154	0.010	24.468
35	10	0	90	0.93	0.42	0.41	0.023	0.002	0.141	0.019	24.444
Shear	**0**	**0**	**100**	**0.93**	**0.41**	**0.41**	**0.019**	**0.010**	**0.019**	**0.010**	**24.468**

Based upon Mitsubishi K13C2U Pitch-based fiber with Fiberite 934 350°F epoxy