agy

S-2 Glass® High Performance Fiber

Solutions for Demanding Applications

S-2 Glass® Fiber

S-2 Glass fiber is a high performance fiber that when compared to conventional glass fiber, provides enhanced fiber properties and greater finished part performance.

AGY offers our customers a variety of solutions by producing both conventional glass fiber (known as E-Glass), S-2 Glass fiber, and other specialty fibers.

For the most demanding applications, AGY produces S-2 Glass fiber, available in the following forms:

- Yarns, including untwisted forming cakes
- Rovings, single-end and assembled
- Chopped fibers

Compared to aramid and carbon fiber, S-2 Glass fiber offers enhanced high performance properties. The newest addition to our S-2 Glass portfolio is our ZenTron single-end rovings. The ZenTron rovings provide high performance, catenary free roving that offer more efficient processing for composites that are pultruded, filament wound or molded from fabrics and braids. (For additional information on ZenTron fiber, contact your AGY representative.)

S-2 Glass fiber has been selected and qualified over other fibers for demanding applications that range from firefighters' air bottles, helicopter blades, surfboards, and running shoes to catalytic filters, aircraft flooring, shipboard armor, and Space Shuttle booster rockets.

S-2 Glass fiber can be certified and meets military specifications MIL-R-60346, Type IV for rovings and MIL-Y-1140H for yarns. It is produced in accordance with the high standards that are part of AGY.

Enhanced Properties to Meet Expanding Demands

What can S-2 Glass fiber do for you?

Compare our material's attributes with your performance requirements and cost targets.

If you have an application which needs the enhanced properties of S-2 Glass fiber, your AGY sales representative—backed by AGY's technical resources—is just a phone call away, and ready to help.

Call **+(1) 803.648.8351**
or email asktheexperts@agy.com

S-2 Glass® Fiber

The High Performance System Solution

AGY's S-2 Glass offers a combination of six vital enhanced properties critical for your demanding applications: strength, impact resistance, stiffness, temperature resistance, fatigue resistance, and both optical and radio transparency.

Compared to conventional glass fiber, the enhanced properties of S-2 Glass fiber result in better weight performance. When compared to aramid and carbon, the enhanced properties of S-2 Glass fibers deliver better cost performance.

Strength
Consistent high performance for reliable and durable finished parts.

Impact Resistance
Offers better fiber toughness, modulus of resilience, and impact deformation, for higher composite durability and damage tolerance.

Stiffness
Delivers 25% more linear-elastic stiffness than conventional glass fiber.

Temperature Resistance
Retains greater fiber tensile strength and stability at elevated temperatures.

Fatigue Resistance
Composite rotors and assemblies can withstand flexural fatigue and a major ballistic impact without catastrophic failure.

Radar Transparency
Delivers 20% lower dielectric constant than conventional E-Glass fiber.

Strength

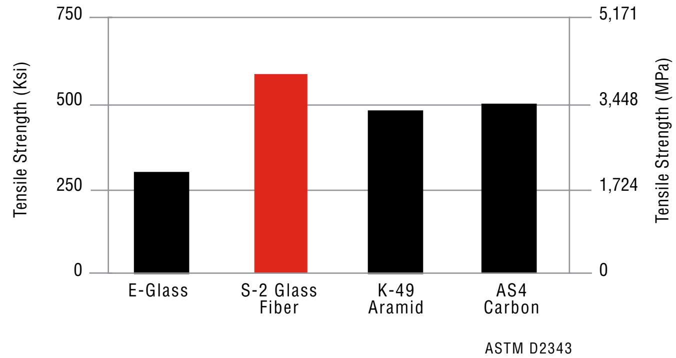
The tensile strength of S-2 Glass fiber provides improved performance for finished parts.

Compared to conventional glass fiber (E-glass), S-2 Glass fiber offers significantly more strength: 60% more tensile strength in resin-impregnated strands. This means it efficiently translates into improved strength for fabrics, prepregs and laminates.

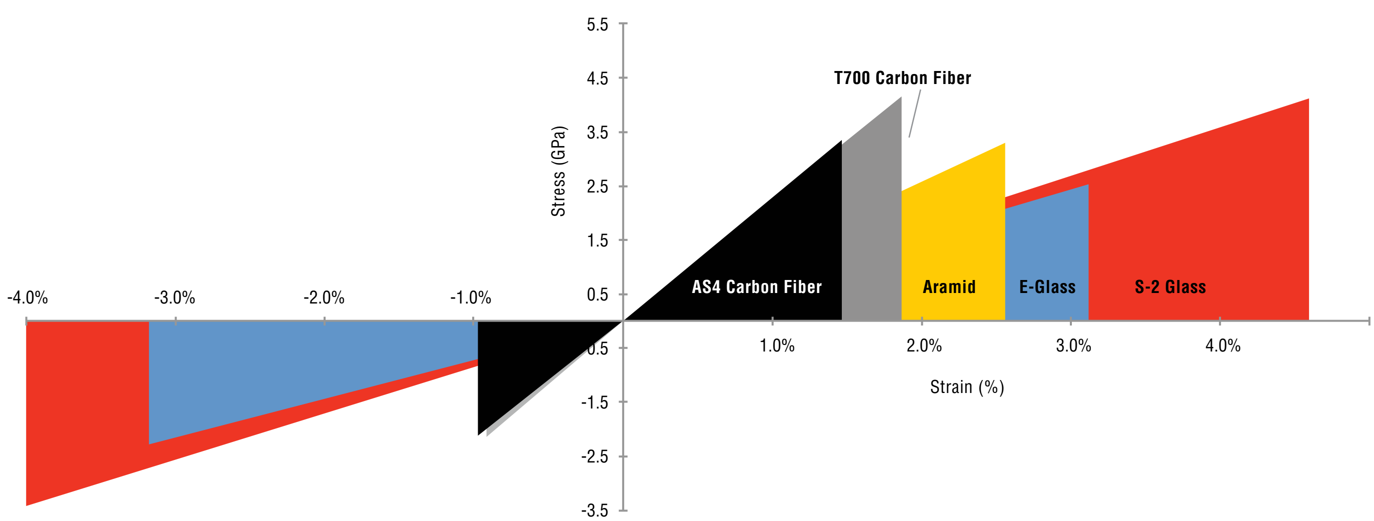
Filament wound structures, such as rocket motor casings, state of the art fighter aircraft fuel tanks, and commercial pressure vessels provide excellent examples. Military and commercial testing standards for aircraft fuel tanks and firefighters' air bottles are extremely rigorous.

They require performance after ballistic impact, intense fire and repeated pressure cycling. S-2 Glass fiber helps meet those rugged standards at minimum weight. Helicopter blades are often made with S-2 Glass because of the high tensile strength and high elongation that S-2 Glass delivers.

Impregnated Strand Tensile Strength



Impregnated Strand Fiber Stress-Strain



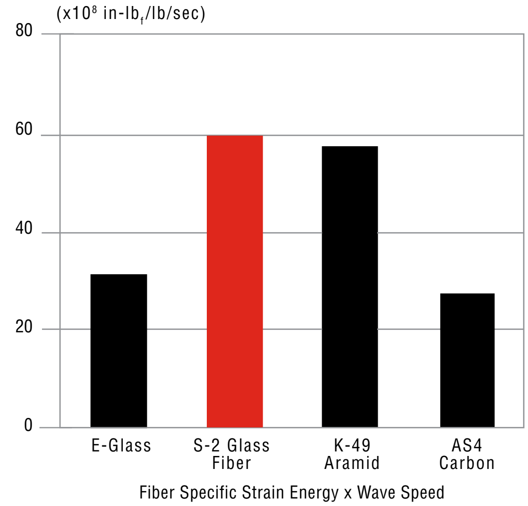
Impact Resistance

Compared to conventional glass fiber, S-2 Glass fiber offers better fiber toughness, modulus of resilience, and impact deformation—characteristics that efficiently translate improved impact capabilities to finished parts.

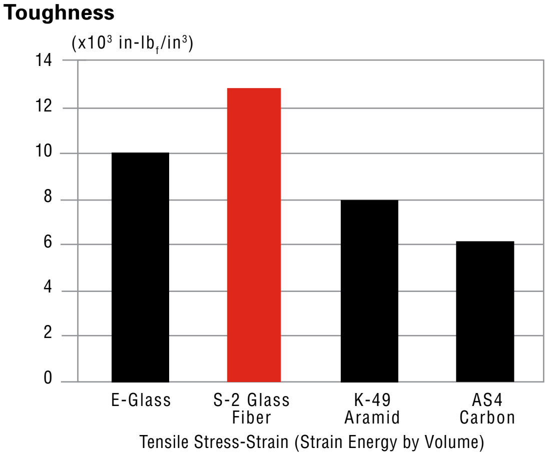
Perhaps the ultimate test for impact resistance is in ballistic protection systems. S-2 Glass fiber properties provide maximum protection at minimum weight and cost. In close cooperation with the U.S. Military, AGY offers a patented S-2 Glass armor system called HJ1. This S-2 Glass armor technology is ballistically rated against numerous threats and is being used to protect crews on land, sea, and in the air.

One example is the UK MoD Foxhound Vehicle. It uses high performance S-2 Glass armor technology can also provide ability to design lighter weight fully structurally capable composite armor systems to replace heavy metal primary structure. On average, a structural S-2 Glass laminate hull system can permit composite hulled combat vehicles that are half the weight of comparable steel hulled equipment, and 30% lighter than comparable aluminum hulled vehicles.

Fiber Impact Deformation



Fiber Toughness



structural composite armor

Stiffness

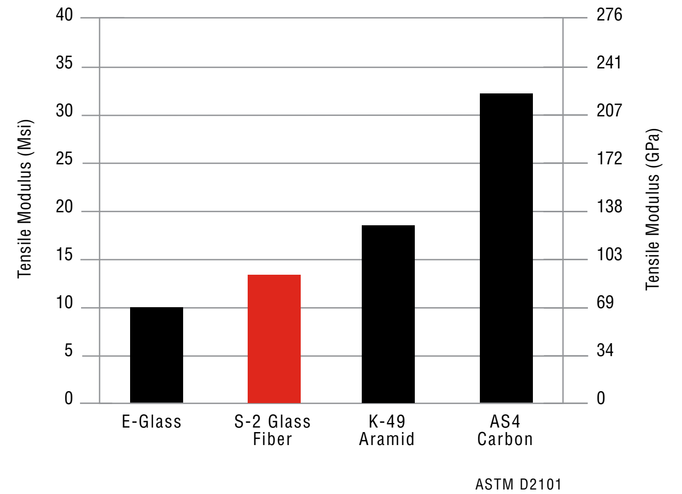
S-2 Glass fiber delivers 25% more stiffness than conventional glass fiber.

The increased stiffness, coupled with enhanced impact resistance, makes S-2 Glass fiber an ideal choice for multiple aircraft applications. Aircraft floors must span supports, take concentrated foot and roller cart traffic, resist fire, corrosion, and moisture—all within specific cost targets.

S-2 Glass is also used in the fuselage of composite commercial aircraft. S-2 Glass is used in fuselage panels that are forward facing, that have the greatest chance of getting hit from foreign objects. The increased stiffness over E-glass fibers make S-2 Glass the best fiber choice for these areas.

Another area on commercial aircraft that uses an extensive amount of S-2 Glass are the luggage bay panels. These panels need to be rigid to resist the big loads that are applied to them during the loading/unloading process, while absorbing the impact energy from these loads.

Fiber Tensile Modulus



Temperature Resistance

S-2 Glass fiber retains greater fiber tensile strength at elevated temperatures than conventional glass fiber, and it performs at up to 760°C (1400°F).

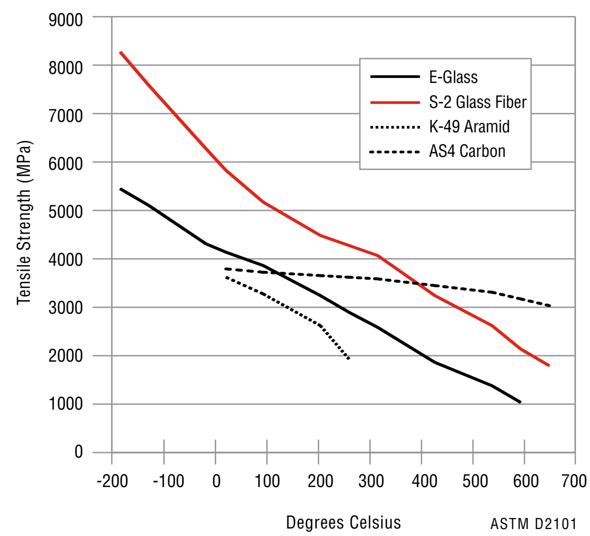
For example, automotive engineers chose gaskets made from S-2 Glass fiber for their passenger car and light truck catalytic converters. The quality fit of the gaskets permits less use of costly precious metals. S-2 Glass fiber's enhanced temperature resistance enables the converter gaskets to perform at the elevated operating temperatures created by today's smaller engines and their hotter exhaust gases.

The burn-through resistance achieved by S-2 Glass fiber, combined with its enhanced stiffness and its impact resistance enables it to pass the FAA NPRM84-11 test. Among others, Boeing utilizes S-2 Glass fiber composite cargo liners.

Enhanced temperature resistance is a critical factor in high performance thermoplastics. AGY has responded to the needs of this market by developing S-2 Glass fiber with our 933 sizing that enables the fiber to be used in higher temperature thermosets (cyanate esters, bismaleimides, phenolics) and thermoplastics (polyimides, PEEK, PEI and LCP). It is particularly well suited for applications where requirements include high strength, structural damage tolerance, dielectric transparency, galvanic corrosion resistance, and zero moisture absorption.

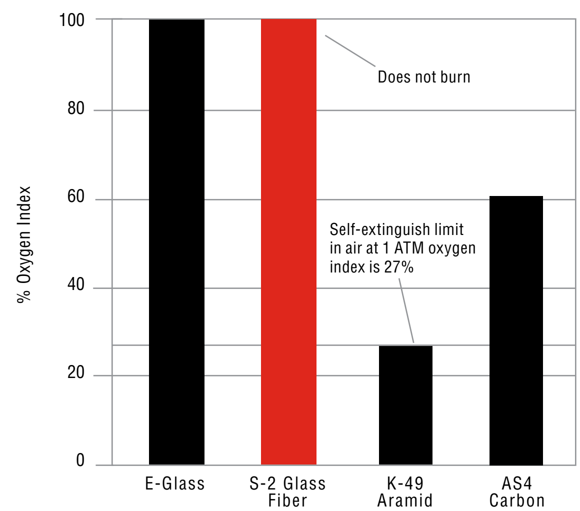
The enhanced temperature capabilities of S-2 Glass fiber also allow it to be used as a reinforcement of certain high temperature ceramic materials such as those used in ceramic cooker hobs.

Fiber Tensile Strength at Temperature



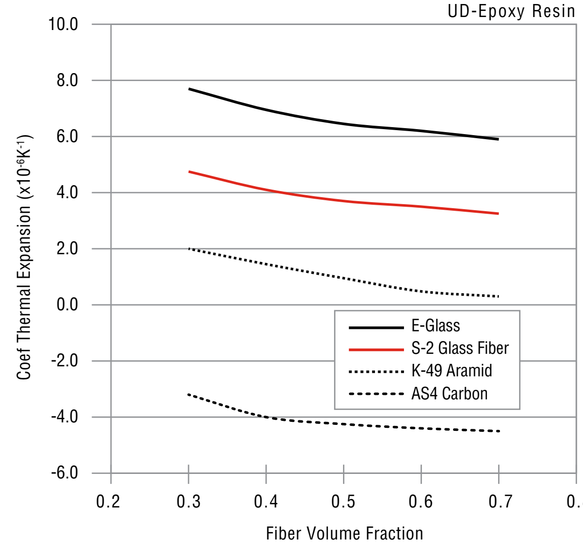
ASTM D2101

Flame resistance



ASTM D2863

Dimensional Stability



ASTM D696

Fatigue Resistance

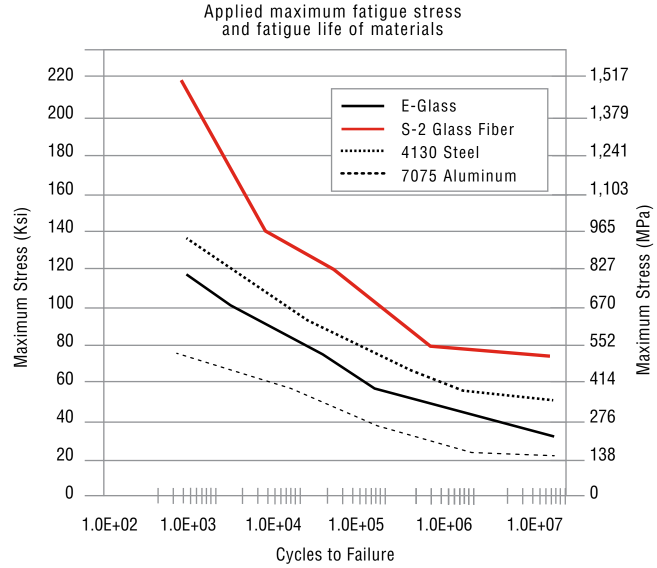
S-2 Glass fiber reinforced composites combine stiffness, strength, impact resistance and temperature resistance with a high level of fatigue resistance (a measurement based on tolerance to damage accumulation).

Because of this, S-2 Glass fiber composites are the material system of choice for helicopter blades and rotor assemblies.

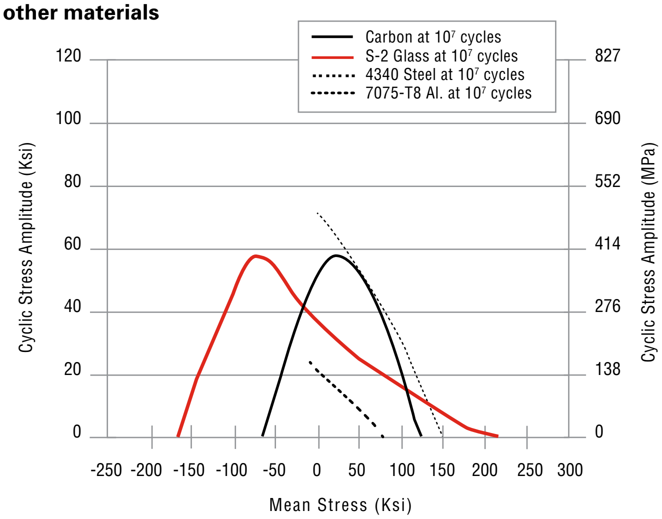
Major helicopter manufacturers, such as Bell and Sikorsky, continue to favor S-2 Glass fiber over metals in their rotor systems. Why? Because composite rotors and assemblies can withstand high levels of tension and flexural fatigue, and a major ballistic impact without catastrophic failure. Composite systems regularly demonstrate a longer hour life, typically by a factor of two or three over metals.

S-2 Glass used as a reinforcement of rubber timing belts also demonstrates significant advantages in fatigue performance over metal chains, especially in the hot/wet and corrosive environment found inside automobile engines.

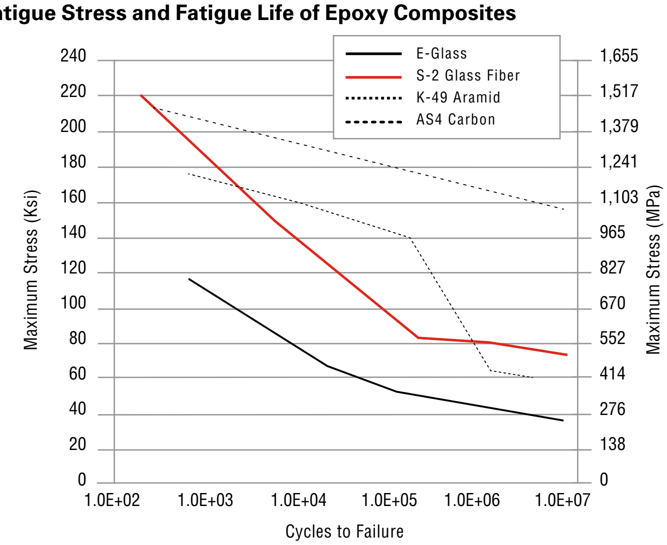
Unidirectional Tension-Tension fatigue



Goodman diagram of S-2 Glass/Epoxy fatigue vs other materials



Unidirectional Tension-Tension (R=0.05) Applied Maximum Fatigue Stress and Fatigue Life of Epoxy Composites



ASTM D3479

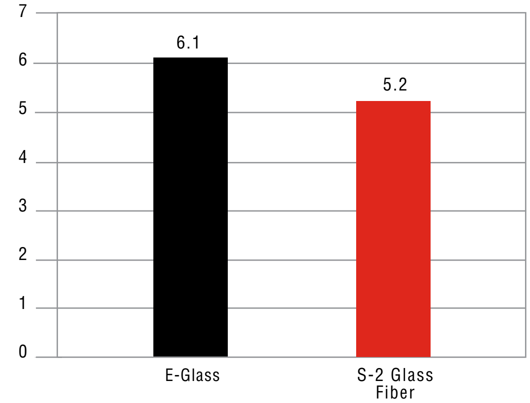
Transparency:
Radio and Optical

S-2 Glass fiber reinforced composites offer electronic transparency. Compared to conventional glass fiber, S-2 Glass fiber delivers a 20% lower dielectric constant. In addition to having better radio transparency, S-2 Glass is also optically transparent and colorless.

This improved transparency—coupled with its inherent stiffness, strength, impact resistance, temperature resistance, and fatigue resistance—makes S-2 Glass fiber a frequent choice for radome applications. The superior mechanical performance allows thinner structures which further enhance transparency. In fact, S-2 Glass fiber contributed greatly to the radome performance of many commercial nose cones.

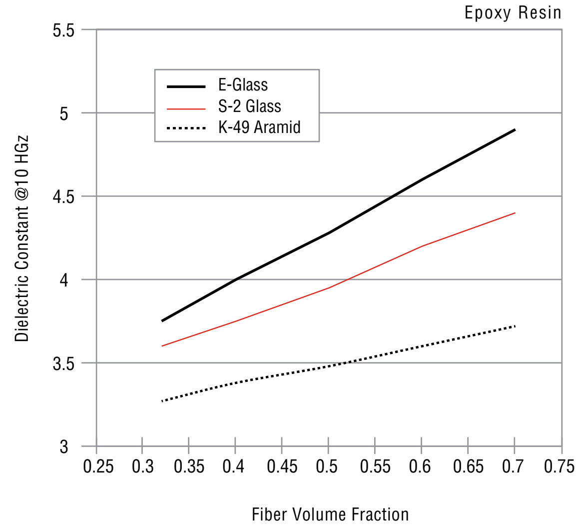
By nature, S-2 Glass is colorless and transparent. When combined with the appropriate resin system, the combination will offer a clear, colorless, transparent composite material that can open up new applications that have never been thought possible in the past.

Fiber Dielectric Constant at 10 GHz



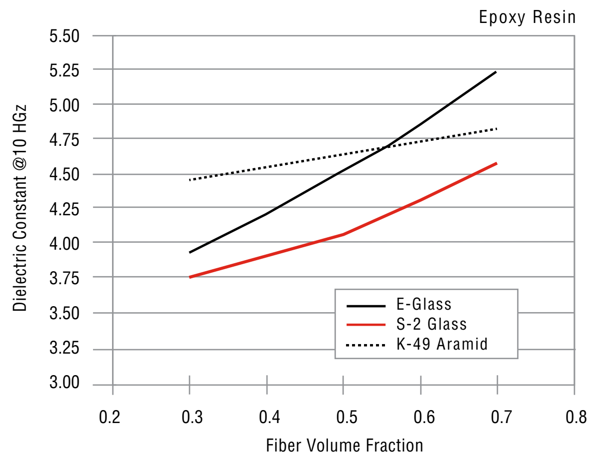
ASTM D150

Dielectric Transparency



ASTM D150

Dielectric Transparency under hot/wet conditions



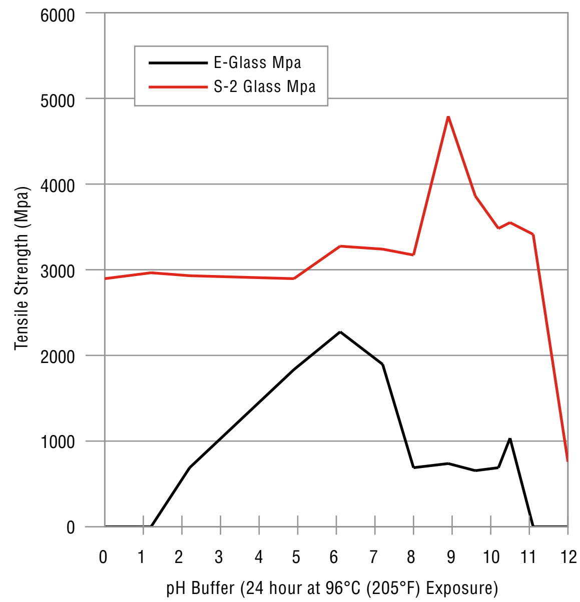
ASTM D150

Corrosion Resistance

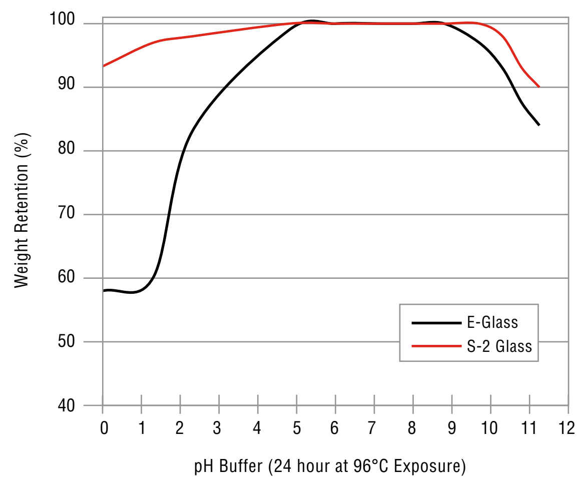
S-2 Glass has far better corrosion resistance when compared to E-glass. For applications that require the S-2 Glass to be in contact with both low pH and high pH materials, S-2 will far outperform E-glass.

To quantify this higher level performance, we look at the weight loss of the glass fiber and the tensile strength of the fibers after being subjected to various levels of pH. The high level of corrosion resistance is used in filtration media applications where the filter elements are exposed to the corrosive chemicals.

Fiber Strength vs pH exposure



Fiber Weight Retention vs pH Exposure



chemical resistant components

Cost Advantage

The unique material properties of S-2 Glass allow it to be the lower cost solution when compared to aramid and carbon fibers. Without jeopardizing performance, engineers are creating more efficient designs with S-2 Glass that reduce weight while meeting the increasingly competitive demands of world markets.

Availability

High performance S-2 Glass fiber is available in the form of rovings (single-end and assembled), yarns, and chopped fibers directly from AGY. It is also available from our customers as fabric, braid or hybrid, as well as prepreg (such as unidirectional, roving, tape and fabric), or co-mingled with other fibers.

Hybridization Further Enhances Your Cost Performance Advantage

Many applications require a balanced set of fiber properties or have lower cost targets. Hybridization (e.g., S-2 Glass fiber/carbon composites) combines materials in such a way that they deliver a desired mix of properties. Various studies have shown significant improvement in impact resistance and damage tolerance of carbon/epoxy laminates with hybrid constructions of 25% S-2 Glass fiber and 75% carbon fiber (wt./wt.).

S-2 GLASS FIBER PRODUCTS

Product Form	Product Number	Available TEX (Yields)	Resin Compatibility	Fabrication Process	Specification Number
Roving – Assembled	365	1980, 660, 400 (250, 750, 1250)	Polyester, Vinyl Ester, Epoxy	Filament winding, weaving, braiding, prepregging, pultrusion, compression and vacuum molding, texturization.	MIL-R-60346C
Roving – Assembled	449	1980, 660, 400 (250, 750, 1250)	Epoxy (Amine), Urethane		
Roving – Assembled	463	1980, 660, 400 (250, 750, 1250)	Epoxy (Anhydride), Phenolic		
Roving – Assembled	933	1600, 660, 400 (310, 750, 1250)	Polyamides, BMI, PEEK, PEI, PPS, PEK, PES, PAI, Epoxies, LCP	Thermoplastic processes	
Roving – Single-end	VE1	2400, 1200 (207, 416)	Vinyl Ester, Polyester		
Roving – Single-end	517	735, 360 (675, 1400)	Epoxy / Polyester, fast wetting		
Roving – Single-end	758	735, 360 (675, 1400)	Epoxy / Polyester, fast wetting		
Roving – Single-end	933	735, 360 (675, 1400)	Polyamides, BMI, PEEK, PEI, PPS, PEK, PES, PAI, Epoxies, LCP		
Roving – Single-end	721B	2060 (250)	Epoxy / Polyester, fast wetting		
Roving – Single-end	561	735, 360 (675, 1400)	High temp. thermoplastics	Thermoplastic processes	
Yarns	636	66 (G75), 33 (G150), 11 (D450)	Starch based, general purpose	Weaving, braiding, knitting, texturizing and cording.	MIL-R-60346C
Yarns	493	66 (G75), 33 (G150)	Epoxy / Polyester		
Yarns	933	66 (G75)	Polyamides, BMI, PEEK, PEI, PPS, PEK, PES, PAI, Epoxies, LCP		
Yarns (Forming cake)	762	22 (E225)	Rubber compatible	Rubber Reinforcement	
Yarns (Forming cake)	933	66 (G75)	Polyamides, BMI, PEEK, PEI, PPS, PEK, PES, PAI, Epoxies, LCP	Thermoplastic processes	
Chopped	528	4 mm (5/32")	Polycarbonate	Injection molding	
Chopped	544	4 mm (5/32")	Nylon		
Chopped	553	4 mm (5/32")	Nylon		
Chopped	599	4 mm (5/32")	Polypropylene		
Chopped	463	4 mm (5/32")	Epoxy (anhydride), Phenolic	Thermoset molding	
Chopped	401	6 mm (¼")	Epoxy / Urethane		
Chopped	402	12 mm (¼")	Starch based, good dispersion	Nonwoven	
Chopped	620-1	6 mm, 12 mm (¼", ½")	Starch based, good dispersion		
Chopped	602	50.8 mm (2")	Starch based, good dispersion		

Pricing information, product data sheets, Customer Acceptance Standards, customer sources and other application-specific information can be obtained from your AGY sales representative.

Typical fiber properties

Property (test standard)	S-2 Glass Fiber*		E-Glass		K-49 Aramid		AS4 Carbon	
Physical	**gm/cm³**	**lb/in³**	**gm/cm³**	**lb/in³**	**gm/cm³**	**lb/in³**	**gm/cm³**	**lb/in³**
Density (ASTM-C693)	2.46–2.49	0.089–0.090	2.55–2.58	0.092–0.093	1.44	0.052	1.8	0.065
Hardness (Moh's scale)	6.5		6.5		N/A		N/A	
Mechanical – Impregnated Strand	**MPa**	**Ksi**	**MPa**	**Ksi**	**MPa**	**Ksi**	**MPa**	**Ksi**
Tensile strength (ASTM D2343) at 22°C (72°F)	3660–4280	530–620	1860–2690	270–390	2900–3620	420–525	3100–3790	450–550
Creep, % of initial strain (ASTM D2990) at 50% of strength, 10,000 hrs	0–3%		0–5%		10–30%		0–2%	
Mechanical – Single Filament	**MPa**	**Ksi**	**MPa**	**Ksi**	**N/A**		**N/A**	
Tensile strength (ASTM D2101)								
at -190°C (-310°F)	8270	1200	5310	770				
at 22°C (72°F)	4590–4830	665–700	3450–3790	500–550				
at 371°C (700°F)	3760	545	2620	380				
at 538°C (1000°F)	2410	350	1720	250				
	GPa	**Msi**	**GPa**	**Msi**	**GPa**	**Msi**	**GPa**	**Msi**
Tensile Modulus of elasticity (ASTM D2101)								
at 22°C (72°F)	86–90	12.5–13	69–72	10–10.5	124–131	18–19	221–234	32–34
at 538°C (1000°F)	89	12.9	81	11.8				
Strain to failure (ASTM D2101)	5.4–5.8%		4.5–4.9%		2.5–2.9%		1.5–1.6%	
	MPa	**Ksi**	**MPa**	**Ksi**	**MPa**	**Ksi**	**MPa**	**Ksi**
Toughness (ASTM D2101)	83–90	12–13	62–69	9–10	48–55	7–8	35–41	5–6
Moisture Regain (ASTM D1909)	0%		0%		3.5%		0%	
Optical								
Refractive index, 589.3 nm (oil immersion)	1.520–1.525		1.547– .562		1.6–2.0		N/A	

** Annealed Bulk Glass Properties by Sonic Resonance at 20°C (68°F) for S-2 Glass fiber.*

Young's Modulus	*13.6 Msi*	*Poisson's Ratio*	*0.23*
Shear Modulus	*5.53 Msi*	*Bulk Density*	*2.488 gm/cm3*

Typical fiber properties (continued)

Property (test standard)	S-2 Glass Fiber**		E-Glass**		K-49 Aramid		AS4 Carbon	
Thermal	**cm/cm•°C**	**in/in•°F**	**cm/cm•°C**	**in/in•°F**	**cm/cm•°C**	**in/in•°F**	**cm/cm•°C**	**in/in•°F**
Linear expansion coefficient (ASTM D696)	1.6×10^{-6} (at -30°C to 250°C)	0.9×10^{-6} (at -20°F to 480°F)	5.4×10^{-6} (at -30°C to 250°C)	3×10^{-6} (at -20°F to 480°F)	-4.3×10^{-6} 41×10^{-6} (at 26°C to 130°C)	-2.4×10^{-6} 23×10^{-6} (at 78°F to 266°F)	-1.1×10^{-6} 17×10^{-6}	-0.6×10^{-6} 9.3×10^{-6}
	Watts/ m•K	**Btu-in/ hr•ft2 °F**	**Watts/ m•K**	**Btu-in/ hr•ft2 °F**	**Watts/ m•K***	**Btu-in/ hr•ft2 °F***	**Watts/ m•K***	**Btu-in/ hr•ft2 °F***
Conductivity, k (ASTM C177)	1.1–1.4	8–10	1–1.3	7–9	0.04–1.4	0.3–10	71–100	50–70
	kJ/kg•K	**Btu/lb °F**	**kJ/kg•K**	**Btu/lb °F**	**kJ/kg•K**	**Btu/lb °F**	**kJ/kg•K**	**Btu/lb °F**
Specific heat at 22°C (72°F) at 200°C (392°F)	0.737 0.820	0.176 0.196	0.807 1.030	0.193 0.247	1.38 2.63	0.33 0.63	0.711 1.210	0.17 0.29
Softening point (ASTM C338)	1056°C	1932°F	846°C	1555°F	(Oxidation above 150°C, 300°F)		(Oxidation above 350°C, 660°F)	
Annealing point (ASTM C336)	816°C	1500°F	657°C	1215°F				
Strain point (ASTM C336)	766°C	1410°F	616°C	1140°F				
Flame resistance Oxygen Index (ASTM D2863)	100%		100%		29%		60%	
Electrical								
Dielectric constant (ASTM D150) at 22°C (72° F) 1 MHz 10 GHz	5.3 5.2		6.6 6.1		4 3.9		Conductive	
Dissipation factor (ASTM D150) at 22°C(72°F) 1 MHz 10 GHz	0.002 0.007		0.003 0.004		0.014 0.010		Conductive	
Volume resistivity (ASTM D257) at 22°C (72°F) 500VDC, Ohm•cm	0.905×10^{13}		0.402×10^{15}		0.5×10^{12}		0.153×10^{-4}	
Surface resistivity (ASTM D257) at 22°C (72°F) 500VDC, Ohm	0.886×10^{13}		0.42×10^{16}		$10^{12} – 10^{14}$		0.1×10^{-4}	
	kV/cm	**Volts/mil**	**kV/cm**	**Volts/mil**				
Dielectric strength volts/mil at 190 mil thick	130	330	103	262	N/A		N/A	
Acoustical	**m/sec**	**ft/sec**	**m/sec**	**ft/sec**	**m/sec**	**ft/sec**	**m/sec**	**ft/sec**
Velocity of sound	5850	19200	5480	18000	2740	9000	5940	19500

**Axial and lateral property respectively due to crystalline orientation.*

***Bulk glass properties considered to be applicable to fiber.*

S-2 Glass Fiber
Unidirectional Composite Properties

Property	ASTM Standard	Epoxy		BMI	
Elastic Constants (22°C/75°F)		**GPa**	**Msi**	**GPa**	**Msi**
Longitudinal modulus, E_L	D3039	53–59	7.7–8.5	59–70	8.6–10.1
Transverse modulus, E_T	D3039	16–20	2.3–2.9	17–21	2.5–3.11
Axial Shear modulus, G_{LT}	D3518	6–9	0.9–1.3	11–21	1.6–3.1
Poisson's ratio, U_{LT}	D3039		0.26–0.28		0.27–0.31
Strength Properties		**MPa**	**Ksi**	**MPa**	**Ksi**
Longitudinal tension, F^{tu}_L	D3039	1540–2000	230–290	1930–2200	280–320
Longitudinal compression, F^{cu}_L	D3410	690–1240	100–180	1240–1516	180–220
Transverse tension, F^{tu}_T	D3039	41–82	6–12	62–96	9–14
Transverse compression, F^{cu}_T	D3410	110–200	16–29	138–207	20–30
In-plane shear, F^{su}_{LT}	D3518	62–165	9–24	124–221	18–32
Interlaminar shear F^{isu}	D2344	155–103	8–15	69–124	10–18
Longitudinal flexural	D790	1240–1720	180–250		
Longitudinal bearing	D953	464–552	68–80		
Ultimate Strain					
Longitudinal tension, OE^{tu}_L	D3039		2.7–3.5%		3.2–3.6%
Longitudinal compression, OE^{cu}_L	D3410		1.1–1.8%		1.7–2.5%
Transverse tension, OE^{tu}_T	D3039		0.25–0.50%		0.4–0.6%
Transverse compression, OE^{cu}_T	D3410		1.1–2%		1.5–2.2%
In-plane shear g^{su}_{LT}	D3518		1.6–2.5%		2–2.5%
Physical Properties					
Fiber volume (%)	D2734		57–63		59–65
Density g/cm³ (lb/in³)	D792		1.96–2.02 (0.071–0.073)		(0.070–0.073)

List of References for Brochure Tables/Graphs

- *DuPont Data Manual for Kevlar® 49 aramid*
- *Hercules Magnamite® product data sheets*
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