A Review of High Temperature Glass Epoxy Laminate Materials

Materials technology continues to evolve offering higher performance materials for more demanding customer applications. Often, manufacturers fail to review their specifications to take advantage of these newer materials that offer improved performance at a lower cost.

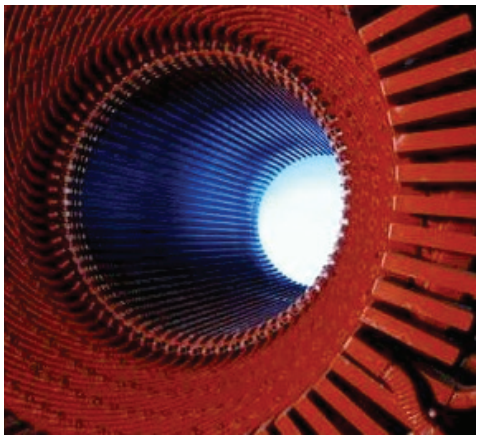
Unfortunately, there is a tremendous amount of confusion in the marketplace regarding the thermal performance of insulation materials. A related document available from The Gund Company, "Thermal Performance of Insulation Materials - A Review of Terminology & Methods", addresses this topic specifically.

Similarly, there is confusion in the electrical insulation marketplace regarding the names, grades, and industry standards given to these materials. Many companies assign their own names to materials and do not make it clear whether their material meets or exceeds the industry standards. A related document available from The Gund Company, "What's In A Name – A Review of Material Data Properties", addresses this topic specifically.

The purpose of this document is to review the common international standards for high temperature, high pressure glass epoxy laminates. The document will review the increasing thermal performance characteristics of the grades available today. Lastly, the document will present side by side test data for several grades of high temperature glass epoxy laminate illustrating typical high temperature laminates.

Manufacturers and designers of electrical equipment have the challenging assignment of understanding the performance of electrical insulation materials using the data that is provided by electrical insulation suppliers. This challenge is daunting when presented with global sourcing options from suppliers that may reference questionable data with no referenced standard or without directly comparable results.

Most electrical insulation suppliers have specifications that are unclear because they mix common industry standard specifications with their own internal specifications. Suppliers often do not have the resources to do internal testing of new materials, so they have no way of validating the performance of their materials. The most widely accepted means of validating the performance of insulation materials from a new source is side by side comparative testing using the most commonly accepted international standards- NEMA and IEC. Unfortunately, this type of testing requires time and money, so it is a step that is often skipped by many suppliers. The Gund Company has offered our test lab services to perform comparative side by side testing of materials to validate the performance of materials.



The generator stator may use high temperature glass epoxy laminate insulation wedges as shown below to secure the conducting bars in the slot

Large steam generators are one example of electrical equipment that relies on relatively high temperature electrical insulation materials. Most electrical equipment relies on the thermal performance of the electrical insulation components and insulation systems for a long life in service.

Particularly when considering high temperature glass fabric epoxy laminate options, the world offers many confusing alternatives. The two most commonly accepted international standards for high pressure laminate materials are the NEMA Standard LI 1 and the IEC Standard 60893. The table below shows the most common standard glass fabric epoxy grades described in these two standards.

Region	Standard	Epoxy	Epoxy FR	155°C Epoxy	155°C Epoxy FR	180°C Epoxy
Europe	IEC 60893	EPGC 201	EPGC 202	EPGC 203	EPGC 204	EPGC 308
North America	NEMA LI1	G10	FR4	G11	FR5	--

Table 1 - Comparison of IEC

The most common glass epoxy laminate specifications are G-10, FR4, G-11, and FR5 provided in NEMA LI-1. In the NEMA Standard, there is not a "Performance Requirement" for the temperature index of these materials. There is a "general guide" for design with a reference to a temperature index of 130°C provided as "authorized engineering information". Thus, the NEMA specification does not require a temperature index of 130°C, but it sets the expectation that a material should have that property. This means that a grade of material could be certified to NEMA properties without achieving that temperature index. G-10 and FR4 have a typical temperature index of 130°C. G-11 and FR5 have a typical temperature index of 155°C and are thus considered "high temperature glass epoxy laminates". FR4 and FR5 both have a Flammability rating of V-1 according to the UL 94 Flammability test, but both grades commonly have halogenated (commonly bromine) resins systems to achieve those flammability ratings.

In IEC 60893, the most common glass epoxy laminate specifications are EPGC 201 (G-10), EPGC 202 (FR4), EPGC 203 (G-11), and EPGC 204 (FR5). The IEC standard also includes a Grade EPGC 308 which references a temperature index of 180°C though the NEMA standard has no equivalent grade. This grade is also very common, and in North America is commonly referred to as "Class H" or "180°C" G11.

NEMA G-11 was originally developed as a high temperature version of the glass epoxy laminate, G-10. Essentially, the requirements of G-10 are the same as G-11 with the addition of a 150°C flexural strength requirement. Similarly, the IEC Grade EPGC 201 (G-10) was given a requirement for a higher flexural strength at 150°C resulting in the new IEC Grade EPGC 203 (G-11).

Grade[1]	G10	G11	EPGC 201	EPGC 203	EPGC 308
Min Breakdown Voltage	45 kV	45 kV	35 kV	35 kV	35 kV
Max Permittivity/ Dissipation Factor	5.20/.025	5.20/.025	N/A	N/A	N/A
Min Izod Impact (length)	7.0 ft-lb/in	7.0 ft-lb/in	34 kJ/m^2	34 kJ/m^2	34 kJ/m^2
Min Flex Strength 23°C (length)	55 ksi (380 MPa)	55 ksi (380 MPa)	49.3 ksi (340 MPa)	49.3 ksi (340 MPa)	49.3 ksi (340 MPa)
Min Flex Strength 150°C (length)	N/A	30 ksi (207 MPa)			170 MPa (24.6 ksi)
Max Water Absorption	0.15%	0.15%	22 mg	22 mg	22 mg
Min Thermal Endurance[2]	130°C	155°C	N/A	N/A	180°C

Table 2- Comparison of IEC and NEMA glass epoxy requirements for 3mm (1/8") thick sheet material

1-All properties are at room temperature unless otherwise noted. Requirements of properties at different temperatures may not be shown. Note that ISO and ASTM test methods may vary slightly. Hence the difference in some properties which cannot be converted for comparison.
2-Note that thermal class or thermal endurance is not required by NEMA. It is only shown as "Authorized Engineering Data" or a typical value.

Originally, NEMA G11 and IEC EPGC 203 manufacturers provided grades with temperature indices of 155°C. As technology has advanced in the last 10 years, leading North American and European manufacturers began to provide G-11 and EPGC 203 grades with Relative Temperature Indexes (RTI's) very near or beyond 180°C. These grades no longer carry a premium cost and so offer a premium level of thermal performance at a very attractive cost. However, many electrical equipment manufacturers have been slow to update their specifications or approve these new materials that offer premium performance at no additional cost.

Some insulation suppliers try to keep up with the higher temperature performance material trend by claiming performance that they have not achieved. This lack of discipline has resulted in confusion regarding the temperature performance of glass epoxy laminates. Lab testing has proven that not all grades of glass epoxy perform equally at elevated temperatures.

For this reason, The Gund Company recommends performance verification through side by side lab testing evaluation. The TGC materials lab has tested products claiming to be G-11 from over a dozen different international suppliers. This testing has provided us insight into the variability that can be found when sourcing materials such as G-11 from laminate suppliers worldwide.

A high pressure laminate producer can quite easily meet the specifications of "G-11" or "EPGC 203" by adding some higher Tg (glass transition temperature) epoxy resin to a standard G-10 formula. This practice can certainly increase the high temperature flexural strength enough to pass the NEMA and IEC requirements. However, this practice of blending in higher Tg resin doesn't create a thermally stable epoxy thermoset matrix that can withstand high temperatures over long periods of time. The Gund Company lab studies have shown that while most of the "G-11 products" are passing the 150°C flexural requirement, they do not perform well under thermal endurance testing at elevated temperatures beyond 150°C (See table 3).

Sample	G-11/EPGC 308		#1 North Am.	#2 North Am.	#1 Europe	#2 Europe	#2 Asia	# 3 Asia	#4 Asia	South Am.
	ksi	MPa	G11	G11	EPGC 308	EPGC 308	EPGC 308	EPGC 203	EPGC 203	G11
150C Flex Strength ksi (MPa)	30 min	170 min	42.9 (296) Pass	32.4 (223) Pass	46.3 (319) Pass	49.6 (342) Pass	38.1 (263) Pass	8.5 (58) Fail	33.8 (233) Pass	26.2 (181) Fail

Table 3- Comparison data showing different G11 or EPGC 203/308 materials using 150°C flex strength (G11 min 30 ksi).

Many insulation users today are switching to class H (180°C) G-11 or IEC Grade EPGC 308 for today's high performance electrical machines. The Gund Company uses the thermal endurance testing standards ASTM 2304 and UL746E as a guide to qualify a material as class H (180°C RTI). According to these standards, the life of an insulating material can be defined when a selected property reaches 50% of its original unconditioned value. The standard requires testing at 50 degrees above the RTI rating of the material. In the example shown below, The Gund Company tested dielectric and flexural strength thermal endurance for three G11 materials. The control in the study is a G11 grade with a known RTI of >180°C.

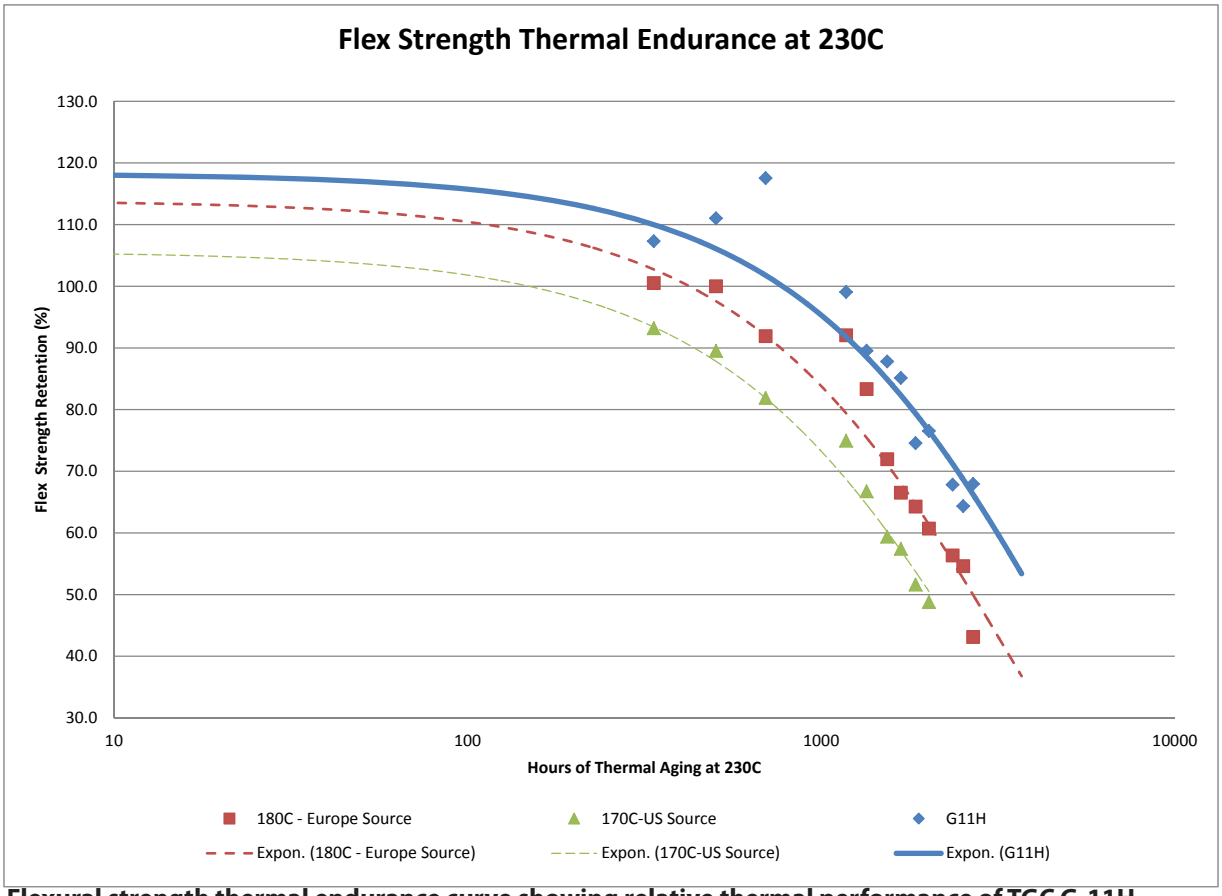


Figure 1- Flexural strength thermal endurance curve showing relative thermal performance of TGC G-11H

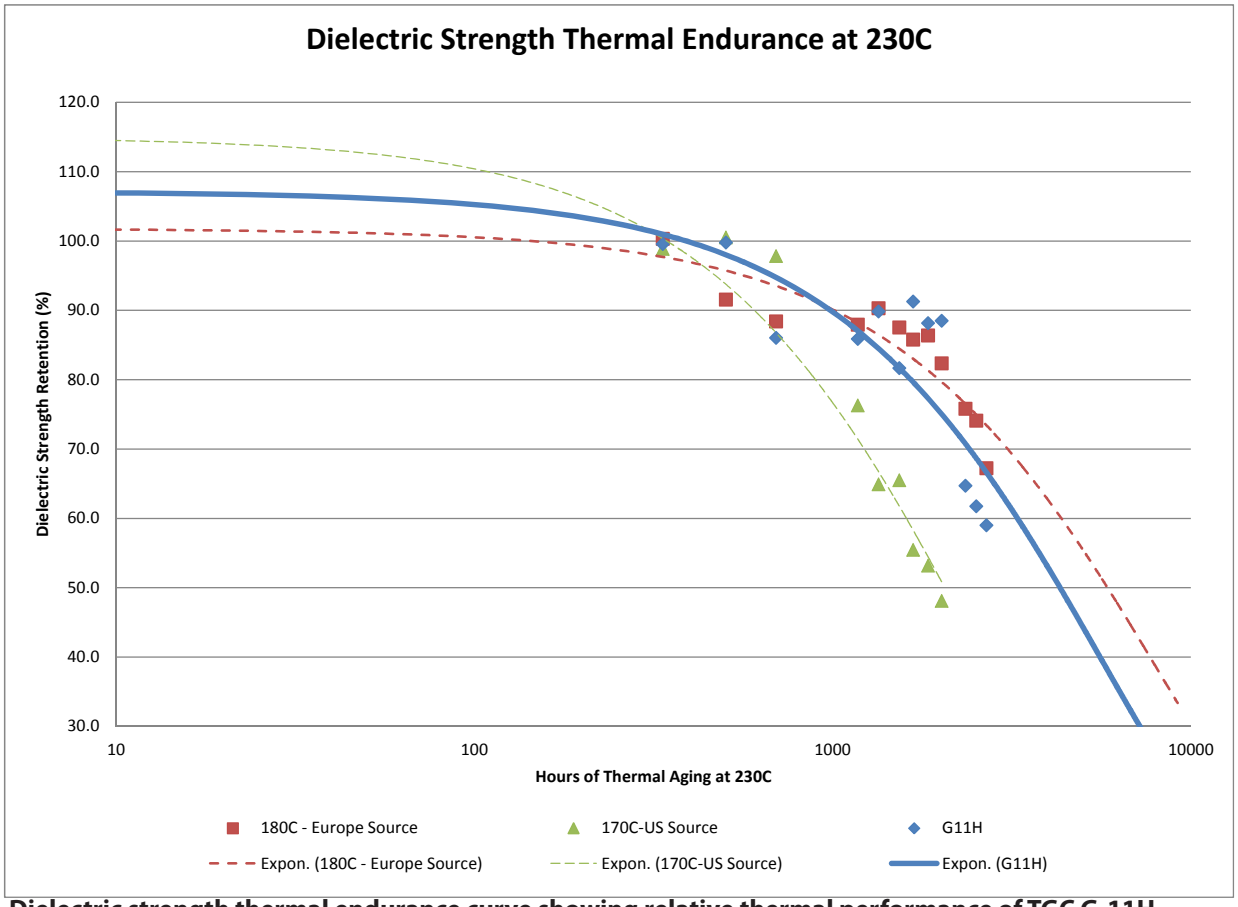


Figure 2- Dielectric strength thermal endurance curve showing relative thermal performance of TGC G-11H

The G-11 produced by an Asian laminate supplier (Asia #4) was tested under the same thermal endurance conditions and only had 34% retention of its original dielectric strength after 6 days (144 hours). The flexural strength retention was even worse at 12% of its original strength. The picture below illustrates the delamination of this product due to the resin degradation.

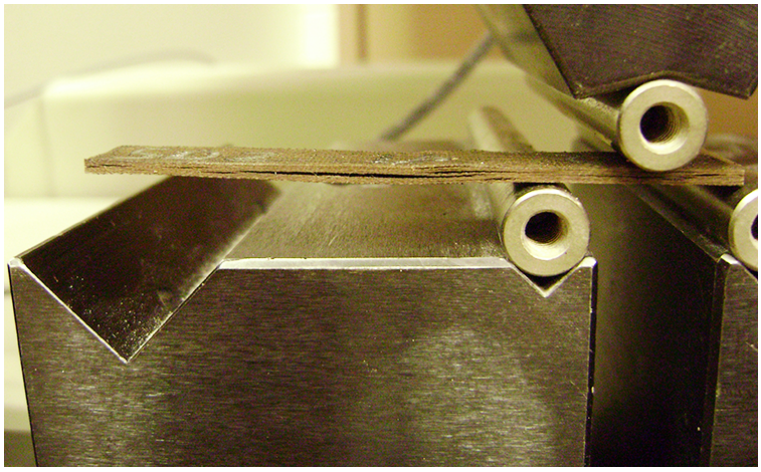


Figure 3 - Thermal endurance sample of Asian produced G-11 after only 6 days of testing at 230°C (Single piece).

The control samples show no signs of delamination or warping after 34 days of exposure to 230°C.

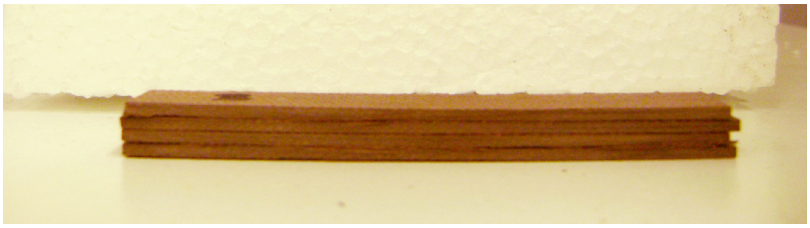


Figure 4 - Control material after 34 days treatment at 230°C (Four pieces stacked).

The Gund Company continues to seek out and qualify the best global suppliers of electrical insulation materials to offer those materials to our customers. Our latest G-11 offering, provides the highest mechanical, electrical, and thermal performance in the industry at an economical price. The Gund Company's Grade G-11 can often replace polyimide and BMI (Bismaleimide) resin thermoset laminates at a significant cost savings. TGC G-11 can provide higher performance and can be substituted for EPGM203, EPGC 203, EPGC 308 and standard G-11 at no additional cost in most cases.

Although G-11 is produced to a standard, the performance between one G-11 and another can often be significantly different. By asking for class H (180°C) G-11 or EPGC 308, the user can ensure they are getting the best quality G-11 which will have the highest thermal performance. This performance can be achieved at a reasonable cost compared to historical high temperature electrical insulation materials.

	TGC G-11	Polyimide (PIGC)	Bismaleimide (BMI)	EPGM 203	EPGC 203	EPGC 308
Flex Strength (at 23C)	486MPa	400 MPa	400 MPa	380 MPa	350 MPa	400 MPa
Flex Strength (at 150C)	276 MPa	200 MPa	200 MPa[1]	190 MPa	207 MPa	200 MPa
Breakdown Voltage	>50 kV	45 kV	49 kV	50 kV	50 kV	50 kV
Dielectric Strength	22 kV/m	20 kV/m	15 kV/m	20 kV/m	15 kV/m	13 kV/m
Permittivity @ 1 MHz	4.5	4.8	4.66	<5	<5.5	4.6
Relative Temperature Index	180°C	200°C	180°C	155°C	155°C	180°C

[1] tested at 200°C

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Item:	G-11H from The Gund Company			
Description:	G-11H from The Gund Company is a Class H, 180 °C Rated NEMA Grade G11 produced using woven glass cloth and high temperature epoxy resin. The material has the ability to maintain excellent mechanical, electrical, and physical properties at elevated temperatures to 180°C. G-11H from The Gund Company is RoHS and REACH compliant toensure reliability, safety, and consistency.			
Standards:	NEMA LI-1: Grade G-11		IEC 60893: EP GC 308 & 203 (sheet) IEC 61212: EPGC22 (tube)	
Availability:	Laminate Sheets:	Thickness:	English Units (in): .010 to 5.0	SI Units (mm/cm): 0.25 to 127 (mm)
		Standard Sheet Sizes:	30 x 48, 48 x 60, 48 x 120	76 x 122, 122 x 152, 122 x 305 (cm)
	Fabricated Parts:	The Gund Company custom fabricates insulation materials to the exact specifications and drawings of our customers.		
	Convolute Tubing[1]:	G-11H from The Gund Company is available in an infinite number of combinations of inner diameter/outer diameter per customer requirements.		

[1] Currently there is no standard for NEMA G-11 Tube. All properties meet G10 Class H (180°C) and EPGC22

Key Characteristics	Units - English (SI)	Typical Values
Standard Color	--	Green[2]
Specific Gravity	lbs./in^3 (g/cc)	0.069 (1.9)

[2] Custom colors available upon request

Engineering Properties

Key Characteristics	Test Method	Units - English (SI)	Typical Values
Tensile Strength (0.125") - LW	ASTM D-638	ksi (MPa)	41 (283)
Compressive Strength - ⊥ (0.500")	ASTM D-695	ksi (MPa)	70 (483)
Flexural Modulus (0.062") LW CW	ASTM D-790	ksi (GPa)	4,200 (29) 4,000 (27.6)
Coefficient of Thermal Expansion	--	"/"°C x 10^{-6}	10
Comparative Tracking Index (0.125")	ASTM D-3638	V	180
Dielectric Strength (0.062") Condition A, Oil	ASTM D-149	V/mil	485

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Material Data Sheet

Grade G-11

NEMA LI-1 G-11 Required Properties

Key Characteristics		Test Method	Units	NEMA Required	Typical Values
Breakdown Voltage (0.062") //	Condition A Condition D-48/50	ASTM D-149	kV	45.0 min 40.0 min	>50 >50
Permittivity @ 1MHz (0.125")	Condition A Condition D-24/30	ASTM D-150	--	5.20 5.40	4.7 4.8
Dissipation Factor@ 1MHz (0.187")	Condition A Condition D-24/30	ASTM D-150	--	0.025 max 0.035 max	0.014 0.017
IZOD Impact Strength (0.125")	LW Condition E-48/50 CW Condition E-48/50	ASTM D-256	ft.-lb/in Notched	7.0 min 5.5 min	11 10
Flexural Strength (0.062")	LW Condition A LW Condition A LW Condition E-150-T150	ASTM D-790	ksi (MPa)	60.0 (414) min 50.0 (345) min 30.0 (207) min	80.0 (552) 70.0 (486) 40.0 (276)
Bonding Strength (0.500")	Condition A Condition D-48/50	ASTM D-229	Lb (kg)	1,600 min 1,500 min	2,200 (998) 2,000 (907)
Moisture Absorption (0.062")		ASTM D-570	%	0.25 max	0.01
Flammability (0.250")		UL94	Class	HB	VO[3]

[3] G-11H from The Gund Company is VO at 0.25" and greater thickness. Below this thickness is HB

IEC 60893 EPGC 308 Required properties

Flammability	Test Method	Units	IEC Required	Typical Values
Flexural Strength LW Condition A LW Condition E-150/T-150	ISO 178	MPa	340 min 170 min	486 276
Charpy Impact Strength	ISO 180	kJ/m^2	34 min	45
Perpendicular Electric Strength (90°C in Oil, 1.5mm)	IEC 60243-1	kV/mm	13 min	15
Parallel Breakdown Voltage (Stepped 90°C in Oil, 3mm)	IEC 60243-1	kV	35 min	>45
Insulation Resistance (After Water Immersion)	IEC 60167	MΩ	5×10^4 min	$>10^7$
Thermal Endurance	IEC 60216	°C	180	180
Water Absorption (4mm)	ISO 62	mg	19 max	4.2