Designing with Plastics

Thermosets in Alternative Energy Applications

by Mark Mush

In 2013 Pacific Gas & Electric (PG&E), a West Coast utility, generated 22.5 percent of its power from renewable or alternative forms of energy. With an ever-increasing government mandate requiring more and more efficient manufacturing methods going forward, alternative or renewable energy will continue to be a growing industry.

With this growth, the need for non-metallic materials to make components and parts will follow. Fortunately there is an existing line of materials that are poised to meet this demand and it is a material that has been around for more than 100 years: industrial thermosets. Thermosets meet the needs of the power generation industry for high strength, light weight, moisture resistant and electrically stable materials.

In addition, thermosets are designed for applications that require electrical and/or thermal insulation. While each energy application is different and can involve multiple choices for what material is needed, this should serve as an excellent introduction to get your material process selection started.

First, thermosets differ from "regular" thermoplastics in that once they take their shape, that shape cannot be altered by the reapplication of heat. Apply flames to acetal or nylon and they are going to melt, whereas a thermoset will hold its shape. That ability to maintain its shape while providing for thermal or electrical insulation capabilities makes thermosets ideal materials in energy applications. Thermosets often exhibit much higher strength and stiffness over thermoplastics (see Chart 1).

Secondly, thermosets are divided into two basic groups: phenolic and glass grades. Each is characterized by the cloth type and resin type. Phenolics have as their basic components a paper or cotton cloth fabric and a phenol resin. Glass grades have a form of woven glass cloth with an epoxy resin (for FR4/G-10 or G-11) or a glass melamine resin for G-9 or a silicone resin for G-7. (Knowing that, you can never have a material called "G-10 Phenolic" – it just doesn't exist!)

Finally, a word about NEMA grades. NEMA stands for the National Electrical Manufacturers Association and they set the standards for a material to be called G-10, G-11, Grade XXX phenolic and so on. Materials must meet certain standards for physical and electrical properties in order to earn those grade names. If they don't meet the standards, technically the material cannot be called or sold as G-10, for example. If supplied with a material that doesn't meet NEMA standards, an end user might end up with unsatisfactory results. Always ensure that your material meets NEMA standards.

Phenolics are broken out into three primary grades: paper, linen and canvas. Furthermore each of these three materials comes in their own electrical designation: Grade XX for mechanical paper/Grade XXX for electrical, Grade L for mechanical linen/Grade LE for electrical and Grade C for mechanical canvas/Grade CE for electrical. The electrical grades are noted for their strong electrical properties of which the mechanical grades have none.

Phenolic materials are great for low cost applications such as insulators, bushings and sheaves that don't require bulked up mechanical properties such as compressive, flexural and shear strength (more on this shortly). They are typically easier to cut and machine as opposed to glass materials.

The limitations of phenolic become apparent when looking at their maximum operating temperatures: 284°F/140°C for paper and 257°F/125°C for both canvas and linen (both electrical and mechanical grades). Furthermore, if you are looking for a material with very strong compressive strength (psi), for

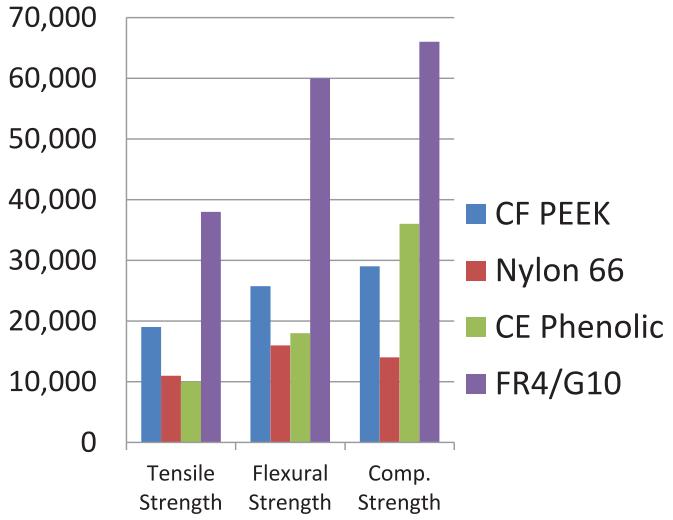

Chart 1: A comparison of the material strength (psi) of carbon filled PEEK, Nylon 66, CE Phenolic and FR4/G-10.

example, the strongest phenolic is Grade C at 37,000 psi. The same mechanical limitations apply to tensile, flexural and shear strength when compared to glass based materials. As your temperature and mechanical needs increase, the material selections become more focused on the glass-based materials.

FR4 (flame retardant G-10) typically becomes a logical first and often popular material choice. This grade is extremely high in mechanical strength (compressive strength 63,000 psi), has low moisture absorption and dissipation factors and has superior electrical characteristics which are exhibited over a wide range of temperatures and humidity. FR4 is flame retardant and at 300°F/149°C retains 25 percent of its flexural strength while maintaining all of its electrical properties.

Here's a quick explanation of FR4 or G-10 and what differentiates them: FR-4 has the chemical element Bromine (a Halogen) or other non-Halogens as flame-retardant additives. G-10 does not have any flame retardant additives in its formula. G-10 should never be used where flame retardant properties are required. G-10, however, is excellent in cryogenic applications.

In cases where FR4's mechanical capabilities don't meet the needs for the application, G-11 or high temperature glass epoxy is a possible solution. Similar to FR4, G-11 is more suitable for mechanical/electrical applications at elevated temperatures. This grade maintains more than 50 percent of its flexural strength at 300°F/149°C while maintaining all of its electrical properties. This increase in strength does come at a cost, as G-11 is typically twice the cost of FR4.

Whereas FR4 and G-11 make up the majority of the glass-based materials used for electrical and thermal insulation applications, two other specialized materials have their own niches:

G-9 Glass Melamine — A continuously woven fabric laminated with melamine resin G-9 has good mechanical properties plus high resistance to flame, heat, arcing and most strong alkali solutions. It is recommended for use when good mechanical strength and superb electrical properties are required under wet conditions.

G-7 High Temperature Glass Silicone — A continuously woven glass fabric laminated with a silicone resin produces the most temperature resistant grade of glass epoxy. This grade is self-extinguishing, has good electrical properties under humid conditions and has excellent heat and arc resistance. This material can be used where resistance to continuous operating temperatures exceeding 425°F/218°C is required.

While the physical properties of thermoset materials differ from traditional thermoplastics, the same principle guides your material selection process: As the performance needs increase, a stronger and better material is required. While the above is merely a quick introduction to thermoset materials do keep in mind that they are often the best and sometimes only choice for an application that requires thermal and/or electrical insulation characteristics.

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Material Specifications Data Sheet

	PAPER PHENOLIC XX	PAPER PHENOLIC XXX	CANVAS PHENOLIC C	CANVAS PHENOLIC CE	LINEN PHENOLIC L	LINEN PHENOLIC LE	GLASS PHENOLIC G-3	GLASS MELAMINE G-9	GLASS EPOXY G-10/FR4	GLASS EPOXY G-11	GLASS SILICONE G-7
MILITARY/FED SPEC	Mil-I-24768/11 Type PBG	Mil-I-24768/10 Type PBE	Mil-I-24768/16 Type FBM	Mil-I-24768/14 Type FBG	Mil-I-24768/15 Type FBI	Mil-I-24768/13 Type FBE	Mil-I-24768/18 Type GPG	Mil-I-24768/1 Type GME	Mil-I-24768/27 Type GEE-F	Mil-I-24768/3 Type GEB	Mil-I-24768/17 Type GSG
SPECIFIC GRAVITY	1.35	1.38	1.35	1.37	1.34	1.34	1.85	1.85	1.85	1.82	1.78
TENSILE STRENGTH (psi)	17,000	13,000	11,200	10,000	14,000	13,000	42,000	39,000	38,000	37,000	18,000
COMP. STRENGTH (psi)	35,000	35,000	37,000	36,000	35,000	36,000	76,000	70,000	66,000	63,000	45,000
FLEXURAL STRENGTH (psi)	34,000	22,000	18,000	17,000	23,000	18,000	55,000	55,000	60,000	75,000	25,000
HARDNESS, M SCALE	120	101	103	100	105	100	110	115	115	112	105
BOND STRENGTH (psi)	1500	1200	2,000	1900	1,700	1900	1,500	1900	2300	2200	900
SHEAR STRENGTH (psi)	11,500	12,800	14,000	14,000	13,500	13,500	18,000	18,000	21,500	22,000	17,000
DISSIPATION FACTOR 10^6cycles, Cond A	0.040	0.035	-	0.048	-	0.065	0.023	0.015	0.032	0.020	0.003
DIELECTRIC CONSTANT 10^6 cycles, Cond A	5.30	5.10	-	5.50	-	5.70	7.30	7.00	4.80	5.00	4.20
ELECTRIC STRENGTH V/MIL Cond A	750	700	-	550	-	625	600	450	800	900	400
FLAMMABILITY RATING	94HB	94HB	94HB	94HB	94HB	94HB	94HB	94V-O	94V-O	94HB	94V-O
MAX OPER. TEMP ºC	140	140	125	125	125	125	140	140	140	180	220
COEFF. THERMAL EXP. IN/IN/ºC X 10-5	1.20	1.50	1.10	2.00	1.04	1.80	15.00	1.50	1.00	1.10	1.00
WATER ABSORBTION % - 24 hrs	2.00	0.57	1.60	2.00	1.40	1.90	2.00	0.60	0.10	0.20	0.20

All values given are average based on test samples. The performance characteristics attributed to the products described herein are based on assumptions of general and reasonable use. As results cannot be predicted or guaranteed for any specific set of conditions, each user should make their own determination of these products' suitability for their particular application. 08/2014

A material specification data sheet from Atlas Fibre Company.