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Advanced Reinforcement Technology Presents New Design Opportunities for Printed Circuit Boards

John Kuhn
Dielectric Solutions, LLC
East Butler, PA

Abstract
An innovative approach to glass fiber reinforcement in laminates offers a flatter, thinner weave that result in a smoother, more uniform surface for mechanical and laser drilling as well as improved dimensional stability. The manufacturing process has been completely redesigned to be more efficient and flexible. Glass fabric produced with this new process offers superior properties for high performance circuitry, including lower Dk and Df values, enhanced PTFE compatibility and the opportunity for improved CAF resistance.

Background

Traditional fiber glass fabric technology has remained essentially unchanged for over 30 years. The glass composition, applied chemistries, yarn configurations and woven fabric constructions are basically the same as those used in the 1970s. Glass yarn and fabric production technology is a direct outgrowth of the traditional textile industry. The established infrastructure simply took on the task of servicing a rapidly growing glass fabric industry and equipment designed for weaving cotton and synthetics was adapted to glass yarns with minimal changes.

Prior to the development of large scale integration in electronics, woven glass fabric was used for many years as electrical insulation, as well as in curtains and drapes. Meanwhile, the composites industry was bringing science to bear on reinforced polymer technology, and glass fiber became firmly established as the dominant reinforcement medium. Based on strength to weight ratio, glass reinforced composites are stronger than steel and have displaced metal in many weight-sensitive applications.

But electrical laminate applications are less demanding in terms of strength and weight with more importance given to chemical and electrical properties. For example, a structural composite application would never use glass fibers that were originally coated with food starch and vegetable oil (the standard sizing ingredients used for fiberglass weaving). These ingredients are not chemically compatible with polymer resins and the subsequent removal of these chemicals causes a significant reduction in structural properties. PCB laminate, on the other hand, must withstand multiple immersions in chemically demanding aqueous processes, followed by the extreme temperature fluctuations of soldering. The end product must still possess excellent electrical properties.

In the face of the diverging requirements seen in the composites and electronics industries, it is not difficult to understand why the electronics industry has been slow to take advantage of technical advances in polymer reinforcement. However, by applying the idea of compatible coatings from the composites industry and combining it with new weaving technology, an improved glass fabric has been developed with specific application to the electronics industry.

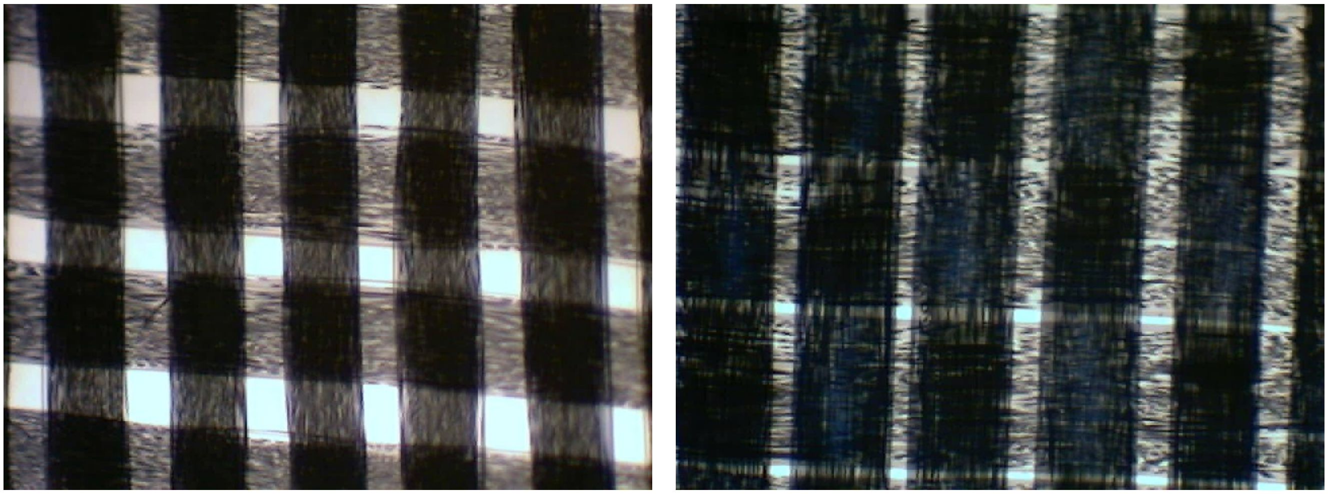
An excellent description and overview of the traditional glass fiber production and fabric weaving process is given by Eng.[1]

Process

A three-pronged approach has been developed to address a number of issues associated with glass fabric manufacture. The fiberglass forming and weaving processes have been integrated into a single facility. The application of a dual-purpose finish has been coupled with twist free weaving to create unique fabrics with superior properties for today’s demanding electronics applications.

Twist free weaving - One of the most time-consuming, costly and damaging steps in the process of producing glass fiber yarn and fabric is yarn twisting. Yarn is twisted prior to weaving in order to consolidate the glass strand, so that it can be woven into fabric without excessive fiber damage and weave defects. However, the actual twisting can damage the glass filaments and impart a helical spring structure to the fiber bundle. Yarn twisting converts the flat fiber strand into a “rope-like” round strand. Once woven into fabric the twisted yarns form a bump or “knuckle” at every crossover point. These knuckles impart a noticeable 3-dimensional element to the fabric, which is especially visible in certain laminate types.

Through innovative weaving technology, a new process has been developed that completely eliminates yarn twisting in both the X and Y directions. The result is a very flat, ribbon-like glass strand. The twisted yarns have been replaced with unidirectional fibers aligned with the weave axes. The untwisted yarns yield a *thinner, flatter glass fabric* with a smooth, consistent surface. Interstitial spaces in the weave are nearly eliminated and weave knuckles are notably reduced. Glass fibers are more evenly and uniformly distributed across the fabric. This is illustrated in Figures 1 and 2.



a. Traditional 1080 Glass Weave with Silane Finish   b. New, Twist Free 1080 Weave

Figure 1 - Comparison of 1080 Glass Weaves

Direct finish application – All glass fiber products require some form of sizing, or finish, to be applied to the glass. The finish serves two purposes: 1) to lubricate and protect the fibers from fracture during processing, and 2) to interface with the end use application providing good chemical compatibility with the resin or chemical coating that is subsequently applied.

In conventional fabrics, fibers are drawn from molten glass and a starch-oil sizing is applied. This sizing provides mechanical integrity and lubrication for subsequent processing. Warp yarns, corresponding to the grain direction in the laminate, are then coated with a second sizing for additional protection. The sizing applied to the glass fibers is subsequently removed by a thermal decomposition process and the fabric is coated with a silane finish to provide a chemical coupling between the glass surface and the resin matrix.

Therefore, the traditional sizing and finish application requires the following steps:

1. Starch-oil sizing is applied when glass fibers are formed;
2. A second protective finish is applied to the warp yarns;
3. After weaving, both finishes are removed via a thermal decomposition process (700°F for ~3 days);
4. A silane coupling agent is applied that is compatible with the laminate resin material.

Needless to say, this process is time-consuming, costly and inefficient. The heat cleaning step causes a change in the structure of the glass which severely degrades its reinforcing properties. In addition, there is considerable opportunity for incomplete removal of the starch-oil finish, as well as for residues to be left behind. The glass fabric is no longer pristine.

A permanent direct finish technology has been developed that is applied when the fibers are drawn and remains on the glass surface through weaving and resin impregnation by the laminate manufacturer. This single direct finish application not only protects the glass fibers through the weaving process, but also provides the chemical compatibility required for optimal resin coating. Process inefficiencies and material handling are minimized. The damaging heat cleaning step that weakens the glass fabric and also contributes to contamination is eliminated. Furthermore, unlike other glass fabric where the final finish is applied after weaving and largely remains on the surface of the fabric, this direct finish system applies the final finish to *each individual glass filament*, immediately after the fiber is formed. Every pristine fiber is fully coated before being pulled into a bundle. The end result is a stronger fabric with a superior resin-to-glass fiber interface, thereby helping to reduce the incidence of CAF-related failures.[2]

Process integration – Generally, fiberglass producers make the glass fiber, then send it to weavers for production into fabric. The fiberglass producers are large and efficient internally, but the necessary packing/shipping requirements introduce delays. Weavers have large, internally efficient operations, but are not particularly flexible, preferring to create large orders of set weaves.

A number of synergies have been realized by integrating the production of glass fiber yarn with fabric weaving, and streamlining the process, all under one roof: handling of the glass fiber and yarns is greatly reduced; packing, shipping and unpacking have been eliminated; there are no shipping delays between fiber production and weaving. The process integration has eliminated the normal information barriers that would exist between fiber producer and fabric weaver as separate companies. Material flow, product scheduling and quality control are completely integrated across all operations, from raw glass through finished glass fabric. This uniquely flexible and highly efficient process can quickly respond to customer needs for specialty products and/or sudden market changes, while tracking quality to an unprecedented degree.

Material Characteristics

Printed circuit board substrates that utilize this new glass fabric technology are currently under development. While all testing is not yet complete, many of the physical, thermal and electrical properties can be inferred from existing technologies.

Twist free yarns yield a thinner, flatter glass fabric for the same weight and construction. In addition, without the mechanical cabling that occurs in the twisting process, twist free yarns easily separate and allow maximum fiber spreading as illustrated in Figure 1. The measured thickness of the 1080 fabric made with twist free yarn (Figure 1b) is 1.5 mils, as compared to traditional 1080 glass (shown in Figure 1a) which is specified at 2.1 mils.[3] Twist free yarn construction yields a more consistent, more uniform fabric, where weave knuckles are minimized, and glass fibers are more uniformly distributed, resulting in improved drilling and machining characteristics.

This new technology exhibits properties similar to fabrics that were specifically designed to be laser-drillable and are currently available as high end products. Laser-drillable fabrics demonstrate improvements in print-through, laser-drilled hole geometry and plateability, dimensional stability and laser drilling speed.[4] Laser-drillable fabrics reduce print-through due to improved laminate surface planarity and have inherently lower surface roughness when compared to laminate made with traditional glass fabrics.[5] The high strength properties of direct finished fabric, combined with the more uniform distribution of the glass fiber yarns, provides for improved dimensional stability in laminate for circuit board applications.

More recent work has shown a direct impact of fabric weave pattern on impedance and electrical property variations.[6] Localized variations in dielectric constant (Dk) result from the natural difference in woven fabric density (weave knuckles and the interstices between them). This has become a limiting factor in controlled impedance design for traditional glass fabrics.[7] Based on the demonstrated properties of other spread fiber fabrics, the new technology has improved thickness control and reduced variation in glass density, i.e., a much more uniform glass layer. This gives tighter controlled impedance since layer thickness and laminate Dk directly affect the characteristic impedance of balanced circuit traces.

Twist free fabric, with reduced spaces between the fibers, is less porous than traditional glass fabric produced with twisted yarns. Fibers are easily spread for better wet-out, while the direct finish assures optimum coating. The result is a higher quality resin-rich, coated fabric, where pinholes and exposed fibers are minimized. This improved “butter coat” virtually eliminates incidences of “dry glass” and measling.

Direct application of finish provides a better interface between the glass fiber reinforcement and the resin matrix. The thermal decomposition of sizing in traditional fabrics typically leaves a residue, which represents a contaminant on the surface of the glass. But the direct finish process applies the final resin-compatible finish immediately after fiber formation, to a pristine glass surface and to each individual fiber. Not only is wettability and resin impregnation (of the glass bundles) greatly improved, but the highest quality glass-to-resin bond is ensured.

CAF growth typically occurs along the glass fiber reinforcement-to-resin interface in the laminate.[2, 8] Evidence has been found for differences in insulation resistance between warp (grain) and fill direction.[9] Presumably this is due to differences in the chemistry applied to the warp and fill yarns. The improved glass-to-resin interface achieved with a permanent direct finish provides the opportunity to significantly reduce the incidence of CAF related failures in circuit board applications.

Signal integrity applications require laminate with reduced permittivity (Dk) and loss tangent (Df) as compared to conventional E glass. The direct finish, twist free process has also been demonstrated using a proprietary low dielectric glass composition. This approach yields improvement in signal propagation delay and reduction in signal attenuation with further opportunity for circuit miniaturization.[10, 11, 12]

Direct finish technology allows for the customization of resin-compatible finishes. A proprietary direct finish has been developed for polytetrafluoroethylene (PTFE) applications. PTFE reinforcement applications suffer from one of the most beneficial features of PTFE, its chemically inert, non-stick surface. Direct finish technology provides measurably improved bonding to PTFE resin by applying a coupler to each fiber prior to consolidation into a yarn bundle. This is especially important for PTFE where adhesion is primarily mechanical in nature. The PTFE penetrates and locks onto individual glass fibers, as opposed to just the surface of the bundle.

Conclusion

Integration of the glass fiber yarn production with fabric manufacturing has produced a streamlined process that allows unparalleled flexibility in product design and speed to market. By integrating twist free yarns with the application of a direct finish, a glass fabric is produced with superior properties. Three new products have already been introduced, including an E glass fabric for traditional multilayer manufacture, a low Dk fabric, and a PTFE-compatible fabric. Each offers unique opportunities for high performance circuit design and improved manufacturability.

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