Get Wise to Gel Coat Cracks

Characterizing crack defects

By Bob Lacovara, CCM, CCT-I

Gel coat cracking, along with fading or chalking problems, are the nemesis of product warranties for much of the FRP composites industry. While chalking and color change problems may be addressed to some extent by proper end-user maintenance, gel coat cracking is another story. Mild surface issues such as chalking or fading may be remedied by buffing and waxing, however gel coat cracking involves a repair. The problem may range from cosmetic hairline cracks to cracks that extend into the laminate and portend a structural defect.

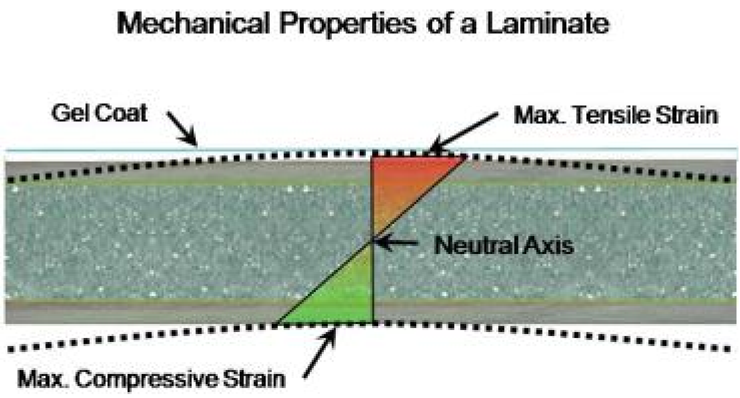
While gel coat cracking may not be viewed as a major factor in the big picture of designing and building boats, it is a big deal to the customer. Consider the retired couple who buys the live-aboard they have dreamed about for years - it becomes their home. It doesn't matter to them if the world's best laminate is underneath the surface; if the gel coat cracks they are upset. Or put yourself in the place of the weekend fisherman who, after motoring around for years in an aluminum runabout, comes to the place where he can afford a new bass boat. It's his toy - it shines, it goes fast, it makes him feel like a real pro. If the gel coat cracks, he is concerned and disappointed. How about the high roller plunks down a several million dollars for the latest sport fishing machine, he expects and demands perfection. Gel coat cracking will not meet his expectations for a boat of this caliber. Of all potential composites related problems, surface cracking is an upfront-in-your-face customer concern.

Hairline cracks in a gel coat surface are usually considered a cosmetic problem, and are treated as such. However, on occasion, gel coat cracking is an indication of underlying structural problems or the result of severe environmental exposure conditions. There are a number of contributing factors to gel coat cracking which include, the basic gel coat formulation, product design, application and operating environment.

Gel Coat Formulation

Gel coat manufacturers walk a fine line in balancing high gloss properties and toughness. Generally speaking it is easier to produce higher gloss in a harder gel coat, while a tougher (and softer) material tends to have less initial gloss. The trade-off is that the harder formulations tend to be more brittle, while the more elastic formulations tend to produce lower gloss. Formulators have developed gel coats which incorporate the best balance of these properties for specific applications. The newest generation gel coat formulations have incorporated enhanced properties, while providing a wider range of toughness and gloss. However, the boat builder must choose carefully in light of the intended use of a product. For example, a high gloss gel coat system suitable for restaurant seating is not suitable for a canoe, which requires flexibility. A careful choice of gel coat type and formulation is required to provide the best fit for each application.

Product Design



Gel coat, by nature of being on the outer surface of a structure, is at the point of the highest mechanical stress within a laminate structure. The tensile or compressive strain in a loaded laminate increases with distance from the neutral axis of the load. In a typical laminate placed under a flexural load, the highest tensile strain is recorded at the top surface, while the highest compressive strain is at the bottom surface. There is no strain at the interior of the laminate, at the neutral axis. Because of the critical positioning of the gel coat film in a laminate structure, both the laminate and the supporting structure must take into account the strain imposed at the surface. Translated into practical terms this means that too much flexing resulting in tensile stress at the gel coat surface can result in cracking.

Gel Coat Application in Production

The primary source of control the boat builder has in influencing gel coat cracking is in the application. The method of application, and conditions surrounding the process, are a major influence on the integrity of the gel coat film. Gel coat film thickness may be the single most important control point in the process. For most gel coats, the range of specified wet applied thickness is between 16 - 24 mils (thousandths of an inch). This range may vary slightly with specially formulated products. However, there is a specific optimum thickness range for each formulation of gel coat required by the manufacturer of the product.

Out-of-spec variations in gel coat thickness can cause several problems ranging from undercure with a thin gel coat, to cracking within a thick gel coat. Another point to note is that the *average* thickness of gel coat on a part may not prevent cracking. For example, if a part averages 18 mils thick, but the corner areas are 26 mils, localized cracking may occur in the over-thick areas. It is important to achieve the proper thickness in the most highly stressed areas of a part.

Because thickness is a critical control point for crack prevention, it is necessary to use the spray process for gel coat application. Although the practice of brushing or rolling gel coat is sometimes used on small parts, this method does not produce gel coat performance acceptable for highly cosmetic products. Gel coat application procedures require measuring the wet film thickness with a mil gauge on every part produced. In addition, critical areas such as corners should be mil gauged on a routine basis.

Gel coat adhesion to the substrate laminate is another factor which influences cracking. The interface bond between the gel coat film and the laminate is another factor in cracking. The forces involved in cyclic loading of a panel, or from expansion and contraction due to temperature changes place stress on the gel coat to laminate interface. In order to achieve an optimum interface bond the preferred window between spraying the gel coat and applying the back-up laminate is 1 ½ hours to 6 hours. A longer dwell time can affect the gel coat/laminate bond. For example, it is not recommended to gel coat a mold at the end of the day and wait until the next morning to apply the skin coat laminate. There have been a number of gel coat cracking warranty problems that have been traced directly to gel coating on Friday afternoon and apply the skin coat laminate on Monday morning.

The ultimate state of cure of the gel coat can also influence cracking or the long-term weathering performance of the surface. Over-initiation (too much catalyst) and/or too thick an application can lead to a brittle gel coat that cracks with little provocation. On the other hand, undercure, resulting from under-initiation (too little catalyst), low shop temperatures or too thin a film will can produce a flexible gel coat. While this more flexible gel coat is not prone to cracking, it is inclined toward premature color degradation, loss of gloss, chalking or chemical attack.

Effects of the Operating Environment

One of the major operating factors involved with gel coat cracking is coefficient of thermal expansion (CTE) of the laminate structure. More simply stated the expansion and contraction of the structure. As the temperature changes so does the size of an object. Small temperature changes yield small, imperceptible changes in dimensions. Large temperature changes or rapid transitions may produce more dramatic effects.

An extreme example of an environment in which gel coat is found is that of high performance sailplanes (gliders). These gel coat finished aircraft have the capability of attaining very high altitudes in atmospheric conditions known as mountain wave. At an altitude of 30,000 feet the temperature may be as low as -30^0 F. The aircraft then descends to ground level temperatures that could be 50^{0}F to 70^{0}F in a relatively short time. That can produce an extreme 100^{0}F temperature differential and gel coat cracks are common in the wings of these aircraft. Even a pick-up truck with a fiberglass truck-cap could be in a 60^{0}F repair shop and drive out into -20^{0}F winter temperatures. While boats, generally speaking, don’t experience these radical temperature swings there is constant movement of the surface associated with the coefficient of thermal expansion as environmental conditions change. Gel coat that is appropriately formulated, and applied properly, performs well within normal temperature environments. However, cracking problems can be evidenced if the production techniques used have not produced the appropriate bond between the gel coat and the underlying laminate.

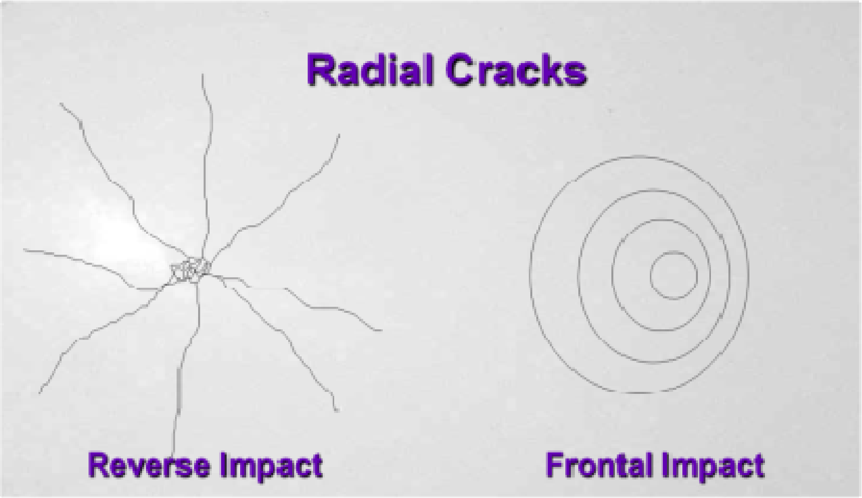
Characterizing Gel Coat Cracks

There are several categories of cracks that are evidenced in gel coat, and each category represents a particular problem or set of problems. A simple visual analysis of these modes of cracking can provide insight into the forces acting on the gel coat surface. Various crack configurations indicate the underlying causes and are vital in determining the root cause issue. In some cases the root problem has little to do with the gel coat and is a manifestation of a structural problem or unanticipated forces moving the substrate.

From a simplistic perspective, it might be said there is only one cause of gel coat cracking - *movement*. If the gel coat surface or the underlying laminate does not move, cracking will not occur. However, the surface will move, whether from temperature change or mechanical force. The mode of movement or the force applied provides a fingerprint that is characterized by the pattern of cracking.

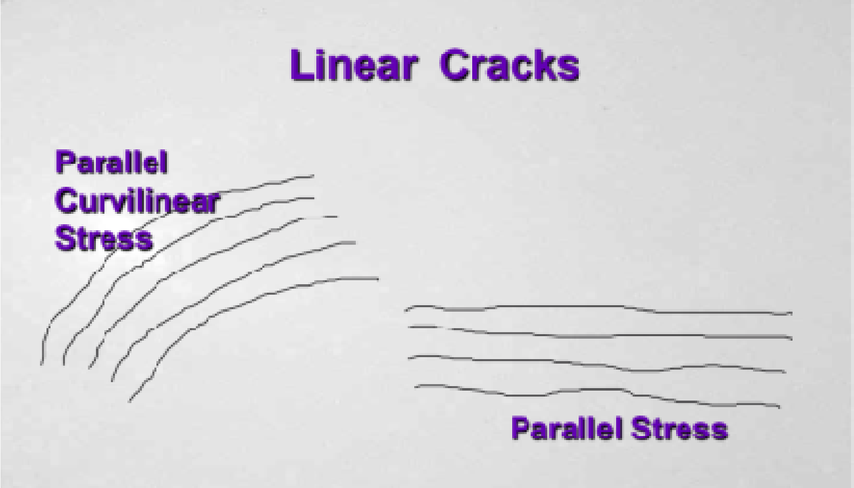
Radial Cracks

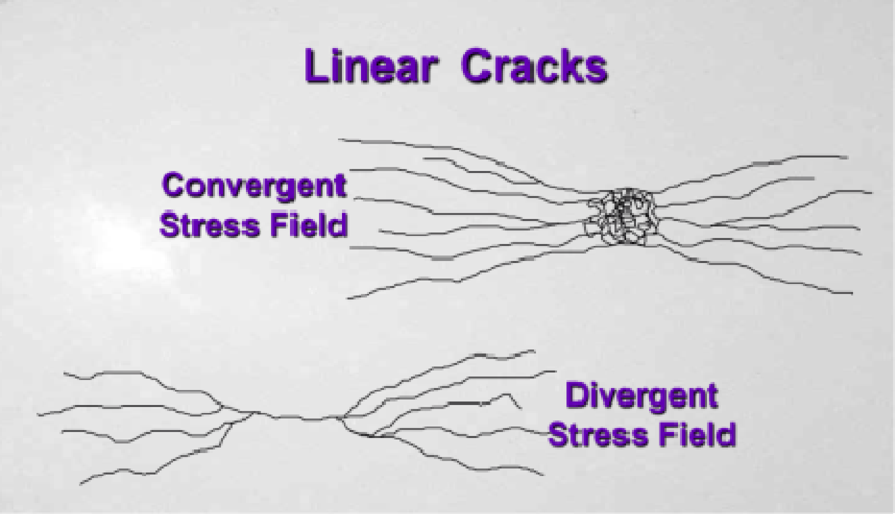
These cracks are associated with impact. Radial cracks provide a positive indication of the direction of the impact. The classic “spider” crack is a result of a reverse impact, or a sharp localized stress riser, from the backside of the laminate. That same force applied to the gel coat side of the laminate produces a frontal impact is indicated by a concentric circle pattern. In this case the diameter of the inner circle has a relationship to the size of the impacting object.



Linear Cracks

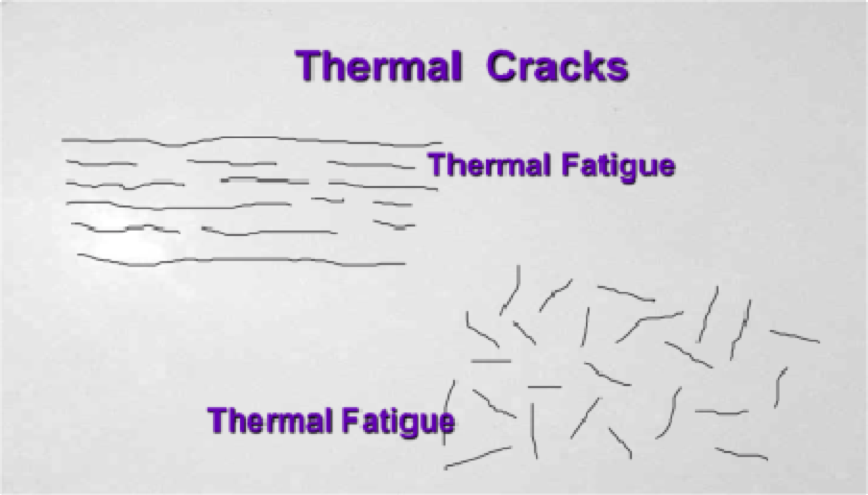
There are two groups of linear cracks – Stress field patterns and parallel stress cracks. The primary cause of these cracks is flexural strain. However, in the case of stress field cracking, an internal structural member, or local stress risers, modifies the parallel pattern into a more complex structure. *Parallel stress* cracks indicate flexural movement perpendicular to the direction of the cracks. *Parallel curvilinear* cracks often indicate a distribution of stress over a panel surface that is supported on two-sides. If the surface is restrained on two-sides the stress pattern will "fan out" creating a "palm leaf" effect. A c*onvergent* stress field develops when flexural strain is interrupted by a structural member. Parallel stress cracks radiate from a localized nucleation. The primary force is deflecting the laminate inward toward the restraining member. The stress flow is interrupted by a concentration around a hard point. In the case of a *divergent* stress field, the laminate is deflected away from the supporting member and the crack propagation is consolidated by a localized hard point.





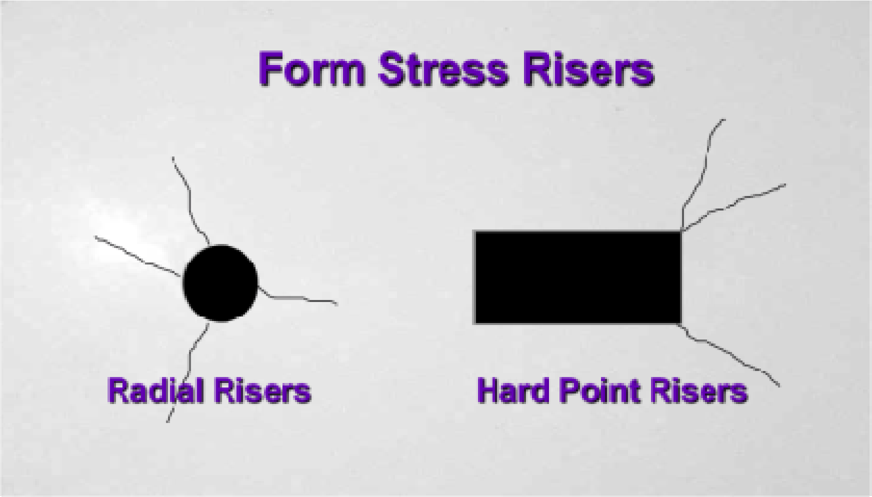
Thermal Fatigue Cracks

Thermal fatigue cracks are a result of repetitive expansion and contraction of the gel coat film. This can be manifested in a parallel pattern or an isotropic (random non-directional) configuration. Thermally induced cracks are characterized by short discontinuous sections, and are usually grouped in a dominate stress field. Isotropic thermal cracks are a result of expansion and contraction within the gel coat film across a broad area. Parallel thermal fatigue cracks are many times propagated by expansion of the surface in conjunction with localized flexural stress.



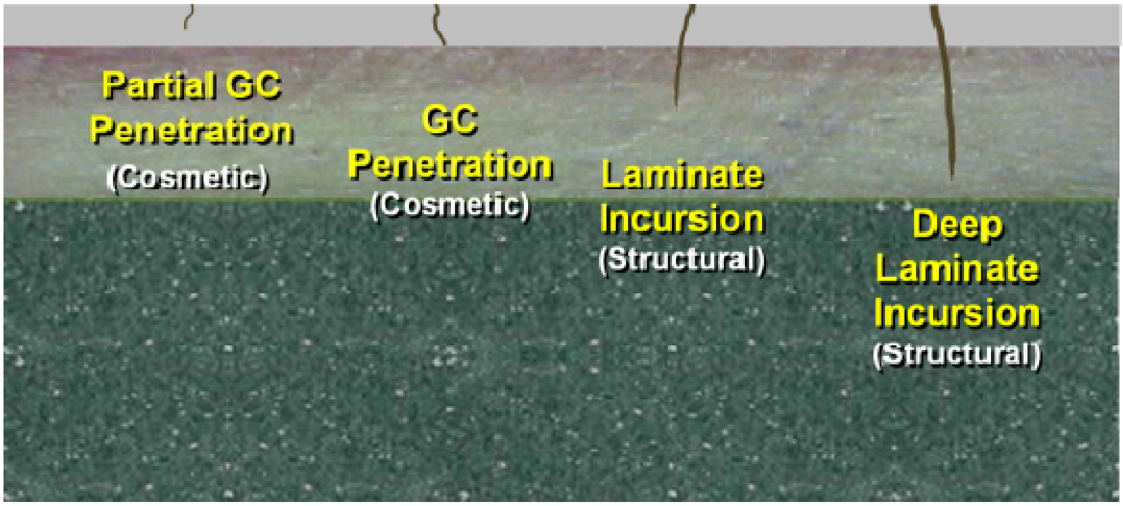
Form Stress Risers

This type of crack is a result of an intervening shape, usually a cut-out, in the surface of a panel. The *form* serves to concentrate strain into a localized area. In the case of a hard point stress riser, even low level strain may result in cracking due to the stress concentration in a very small area. A square shape with sharp corners is a prime candidate for creation of a hard point stress riser. A radial riser may have a different origin. In this case, often a bolt or a hardware fitting exerts a compressive force in the area around a hole. The edge of the hole distends causing high forces around the perimeter of the hole.



Crack Severity Level

In order to develop a uniform characterization for of cracking, a crack severity scale is used to standardize the description of a cracking. The level of penetration through the gel coat film or into the laminate affects the method of repair, which can range from cosmetic to structural. The crack severity scale differentiates two levels of cosmetic cracks, involving only the gel coat film, and two levels of structural cracks, ranging from a minor laminate incursion to significant structural penetration.



Production Techniques to Mitigate Cracking

Minimizing the potential for gel coat cracking involves attention to a number of areas. First is specifying the proper gel coat for the application. A high Barcol hardness gel coat (hard/brittle) gel coat formulation may be suitable for tooling or a component that is not dynamically loaded. Whereas a highly stressed part requires a gel coat with an appropriate modulus of elasticity in order to prevent cracking.

Another consideration is the effect of a structural design on the gel coat surface. Excessive flexing or a flexible panel with rigid corners may contribute to gel coat cracking. With the understanding that the cause of gel coat cracking is surface movement, the structural design needs to address flexural movement.

Gel coat application is critical to crack resistance. Over-thick gel coat is major culprit in cracking. Gel coat film thickness should be a primary focus of quality control. Accurately controlling thickness requires mil gauging as a routine part of the application process. Gel coat curing efficiency is another important factor. Gel time, initiator (catalyst) level, shop temperature, spray gun set-up and spraying technique are all critical factors in producing crack resistant gel coat.

Laminate sequence timing is a contributing performance element. There is a time window from spraying gel coat to laminate application to achieve optimal bonding. Operating outside this window increases the probability of interface bonding problems that contribute to cracking. The optimal timing from gel coat application to the laminating process is 1 ½ to 6 hours.

One very basic principle in production is proper mixing of gel coat in the drum. Unmixed gel coat may have higher styrene content at the top of the drum as compared to the bottom. Styrene is inherently brittle. An unmixed or inadequately mixed drum of material may affect the properties of the gel coat, and contribute to cracking. The lesson is, there are basic principles of FRP production that include material handling and application procedures that prevent a multitude of problems with the product in the field.

Characterizing gel coat crack patterns is relatively straight forward, based on visual analysis. However, diagnosing root cause requires a comprehensive understanding of the forces acting on the structure, the materials system and production techniques.

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About the Author:

Bob Lacovara established Convergent Composites to provide expert services and insight to the composites industry at large. He is the former Director of Technical Services for the American Composites Manufacturers Association, having served upward of 1,000 member companies from 1989 to 2009. In 2010 Lacovara was inducted into the **Composites Hall of Fame** for “a lasting impact that is forever felt by industry professionals”.

In 1989 Lacovara merged his successful consulting practice with Association to create the Technical Services group. He has held positions as General Manager of a corporation producing transportation and aircraft components; and as Operations Manager for a major marine manufacturer. He is a graduate of Rowan University. Lacovara is the originator and developer of the Certified Composites Technician (CCT) program. Over 3,000 participants have earned industry credentials through this widely acknowledged professional development program. In addition, he has served as editor of the *Composites Research Journal*.

As an industry educator he has developed numerous training programs and delivered hundreds of presentations at industry conferences. In the course of this work he has had the opportunity to visit and consult with a large number of composites manufacturing facilities both in the U.S. and abroad. Coupled with his work within the ACMA Technical and Government Affairs Committees, Lacovara has a broad perspective of the composites manufacturing industry.

Lacovara is one of a handful of global experts in the measurement of styrene emissions, having developed the fundamental technology and testing protocols for the quantification of emissions from the composites manufacturing process. These protocols are the centerpiece of industry and EPA emissions factors.

Lacovara has served on the ACMA (formerly CFA) Board of Directors and as President of the Association. He is a recipient of the American Composites Manufacturers Association *President's Award* for outstanding industry service. As a well known author and professional lecturer he has been in the composites industry for over thirty-five years, and maintains a diverse array of activities across the industry.