UV Laser Texturing of CFRP to Achieve High Bonding Strength

The use of Carbon Fiber Reinforced Plastic (CFRP) in various industries such as transportation, clean energy, and consumer products continues to grow due to its unique properties of high strength, light weight, and chemical resistance. The increased use of CFRP will bring its cost down, as more high volume production factories will be built leading to increasing economies of scale. However, not all of the cost of manufacturing with CFRP is due to the material itself. Arising from its unique properties of mechanical hardness, and chemical resistivity, significant fabrication costs are associated with the manufacturing of CFRP components.

It is well known that mechanical cutting and drilling CFRP is costly due to high tool wear and hence, costly consumables, and laser cutting technology is a promising alternative. Laser cutting allows fabrication of parts with detailed, intricate shapes, and laser drilling enables mechanical fastening with bolts and rivets. There are, however, situations in which mechanical fastening is not feasible or desirable, and adhesive bonding is used for joining. In particular the joining of very large structures, such as those commonly found in aerospace and automotive manufacturing, is well-matched to adhesive bonding techniques.

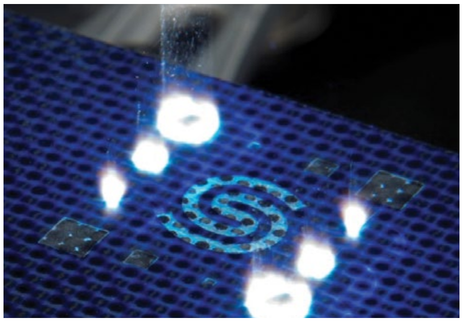

Figure 1: Lasers are increasingly finding use for cutting, drilling, and texturing CFRP components.

For adhesive bonding of CFRP, as well as the bonding of paints and protective or functional coatings, a surface preparation process is required. While the primary purpose is to remove residual contaminants from the mold release agent, there can also be the formation of a surface texture which improves its contact ("wetting", or "wettability") with the liquid adhesives and coatings. The current standard techniques for surface preparation include peel-ply and mechanical abrasion. While both methods yield satisfactory results, they do have their downsides. Peel-ply involves the use of a consumable material to provide a texture and adds an additional manufacturing step during the pre-form/molding stage.

Mechanical abrasion is often a labor-intensive manual process with somewhat poor process control, resulting in high variability in the results and the possibility of undetected damage to the carbon fiber layers near the surface. Furthermore, there is an additional chemical cleaning process that must be undertaken.

Given the non-contact nature and high precision of laser processing, it would seem to be a good fit for surface cleaning/preparation of composite materials. In a collaborative research effort, Spectra-Physics® applications engineers worked with researchers at the Institute for Joining and Welding Technology at the Technical University of Braunschweig (Germany) to investigate the use of Spectra-Physics' state-of-the-art UV (ultraviolet) laser technology for surface preparation of aerospace-grade CFRP material. Using a Quasar® 355-60 laser with TimeShift™ technology, the surfaces of 2 mm thick unidirectional carbon fiber plates were prepared via a laser irradiation process and subsequently joined with high strength aerospace grade adhesive. The samples were tested for lap shear strength using the standard DIN EN 1465 test protocol. Several specimens for each of several laser process parameter sets were tested in order to generate statistically meaningful results. Duplicate specimens were also created for strength testing after a controlled aging process for 1000 hours in a 70 °C, 100% humidity chamber. Strength test data, before and after aging, are show in Figure 2 for the untreated samples, samples treated with a mechanical abrading process that is representative of the current state-of-the-art, and Quasar laser processed samples.

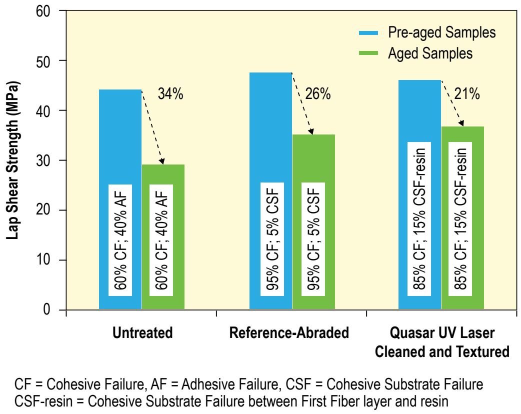

Figure 2: Lap shear strength data for Quasar UV laser processed CFRP plates compared to untreated and mechanically abraded samples, before and after a high temperature aging process.

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The results show that treating the samples definitively results in improvement in the bonding strength. Left untreated, the CFRP plates had a 40% adhesive failure (AF) rate and a 34% drop in strength after the aging process. For the laser prepared and mechanically abraded samples, the initial strength was higher and the reduction in strength after aging was much lower compared to the unprepared samples. Furthermore, the strength after aging was slightly higher with laser prepared samples compared to the abraded samples.

With a laser preparation process, the rate of surface texturing and cleaning is >50 square centimeters per second with 60 W of UV laser power. One reason for the high throughput is that very little material removal is required for proper surface preparation. This means that only a very low energy density (fluence) is required, so that larger focal spot sizes can be used for faster area processing rates. Furthermore, only a single laser pulse is needed to properly prepare the surface area that it irradiates. Therefore no overlapping pulses are needed, and very high scan speeds can be achieved with a high pulse repetition rate laser.

Figure 3 is an optical microscope image of a laser prepared CFRP surface under high magnification. The image shows a very well controlled, deterministic laser texturing of the surface polymer matrix material. Just as importantly, it clearly shows no damage to the individual carbon fibers that are simultaneously irradiated by the beam. It is believed that the fine surface texturing and lack of damage to the fibers contribute to the formation of high strength adhesive bonds.

One of the unique aspects of the Quasar UV laser is that it can output the same 60 W of UV power for a wide range of pulse repetition frequencies (PRFs, 200 kHz to >1 MHz), which means it can accommodate various configurations of beam scanning and focusing optics and still maintain proper fluence and high processing speeds. For example, if a small beam spot is required for the proper texturing effect, then the laser can be operated at very high PRFs allowing very fast scanning in order to maintain high throughputs. Likewise, larger spots can be achieved with the same target energy density by operating the laser at the lower PRFs that correspond to higher pulse energies, hence enabling larger areas to be processed by each laser pulse. Regardless of the optical system configuration and beam scanning equipment employed, Quasar UV laser with TimeShift technology offers a very high level of flexibility, enabling the highest possible area-processing rates.

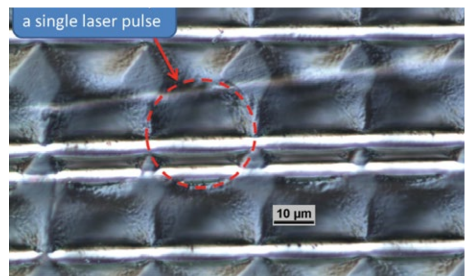

Figure 3: Laser treated surface of CFRP shows clean texturing of the polymer matrix without damage to the individual carbon fibers.

PRODUCTS: *QUASAR 355-45, QUASAR 355-60, QUASAR 532-75, QUASAR 532-95*

The breakthrough performance of the Quasar series leads the industry with unprecedented highest UV average power and energy at high rep rate for fast micromachining. Quasar features novel TimeShift technology for programmable pulse profiles for the ultimate in process speed, flexibility, and control. Quasar 355-60, produces >60 W of UV output power at 200 kHz and 300 kHz, and >300 µJ pulse energy, complementing Spectra-Physics' breakthrough Quasar 355-45 laser. Quasar 355-60 operates over a wide repetition rate range from single-shot to 3.5 MHz, with pulse widths from <2 ns to >100 ns. Quasar 532-95 rounds out the Quasar series with >95 W of green output power. The Quasar family of lasers has excellent beam characteristics and very low noise.

	Quasar 355-45	Quasar 355-60	Quasar 532-75	Quasar 532-95
Wavelength	355 nm	355 nm	532 nm	532 nm
Power	>45 W @ 200 kHz >45 W @ 250 kHz >41 W @ 300 kHz	>60 W @ 200 kHz >60 W @ 1500 kHz ~40 W @ 3000 kHz	>75 W @ 200 kHz	>95 W @ 200 kHz
Repetition Rate	0 to >1.7 MHz	0 to >3.5 MHz	0 to >1.7 MHz	0 to >3.5 MHz
Pulse Width	Programmable with TimeShift			

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