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LASER PROCESSING OF COMPOSITES BASED ON CARBON FIBER

Yurii MLYNCHENKO,
Student,
Igor Sikorsky Kyiv Polytechnic Institute,
mlinchenko.yurii@lll.kpi.ua

Oleksiy MYRONYUK,
PhD, As. Prof.,
Igor Sikorsky Kyiv Polytechnic Institute,
o.myronyuk@kpi.ua

Abstract. The paper describes the use of laser cutting of carbon fiber reinforced composites in various industries. Among the traditional methods of processing, laser cutting has many advantages. Being non-contact, it is wear-free, more controllable, environmentally friendly and has the ability to change machining parameters, which significantly reduces the impact on materials. The variation of lasers types with different impulses: nanosecond, picosecond and femtosecond lasers with pulse durations of -10^{-9}, 10^{-12} and 10^{-15} seconds also significantly reduces the negative impact on the material. Energy of 1 μJ can remove only the outer layer of epoxy resin without damaging the fiber. A pulse energy of 3-4 μJ ensures the elimination of multi-layer fibers, at 5 μJ the material is cut through. IR lasers, with less than 15% absorption by the polymer matrix, heat carbon fibers efficiently, while UV lasers are absorbed predominantly by the resin matrix, offering better cutting potential. Increasing power and speed concurrently enhances efficiency by 25%. Additives like carbon and optically transparent substances such as Fabulase 361 improve laser absorption. Carbon nanotubes integration enhances cutting quality, narrower cuts and reduced heat afected zones compared to non-aligned samples.

Key words: CFRP, femtosecond laser, heat affected zone, laser beam energy absorbers, laser processing, laser pulse energy.

Carbon fiber-reinforced composites are popular in various industries. Composites based on fiber as a reinforcement have high strength, high hardness and lightness, and low thermal expansion. By varying the matrix, unique properties such as corrosion resistance and anti-aging properties can be achieved. That's why these composites are used in the automotive, construction, marine, aviation, aerospace, and electrical industries. Fibers may be either short or continuous.

Continuous fibers provides a better load-bearing capacity, due to the distribution of the load they transmit and retain inside the fibers. The matrix in continuous-fiber composites can also stabilize the composite by distributing the shear forces from fiber to fiber, exhibiting higher strength than short fibers. Short-fiber composites are prone to pull-out by the drawbar, which in turn leads to fracture. There are two critical factors that determine the fiber reinforcement effectiveness: fiber module and fiber length. The higher the module, the more efficient is fiber, therefore high modulus materials such as glass, basalt, aramid and carbon are used for maximum effect. The length of the fiber in discrete fiber composites has to be higher than critical to withstand the pullout. Also, the surface area increases together with a length, which improves the adhesive properties between the components of the composite. Therefore, long fibers are the most effective in improvement of the mechanical properties [1-2].

With the growing demand for such composites in automotive, aerospace and other industries, the need for the quality of their processing grows as well. Nowadays that the vast majority of methods are still traditional, such as conventional turning, high-speed milling, waterjet-controlled laser cutting, electric cutting and ultrasonic vibration cutting. Traditional machining methods are prone to the problems of fiber pull-out, material delamination, resin shedding, low productivity and tool wear. Waterjet cutting has a number of advantages, such as increased cutting speed, reduced thermal stress, but the load and jet dust can lead to moisture accumulation on the surface or cause delamination, and these methods do not allow cutting precise complex shapes. Electrical discharge machining and wire electrical discharge machining are capable of cutting small and complex shapes with precise dimensions, but the high current density can cause the polymer to melt on the cutting surface. Laser cutting in this regard gives better results. Being non-contact, it is wear-free, more controllable, environmentally friendly, and has the ability to change processing parameters such as laser wavelength, pulse duration, laser power, laser energy density, repetition rate, scan rate to significantly reduce or eliminate heat affection zones (HAZ) in the material [3-6].

The early version of the laser was the CO_2 laser. However, when it interacts with materials, there is a bulky zone of thermal influence. Therefore, a significant contribution was the study of the influence of nano, pico, femtosecond lasers on the pre-treatment of CFRP. There are nanosecond, picosecond, and femtosecond lasers with the respective pulse durations -10^{-9}, 10^{-12} and 10^{-15} seconds respectively. When using a picosecond laser, the heat input is significantly less, and accordingly, this making it possible to reduce the thermal-oxidative degradation of the matrix [4].

The technique of surface microphotographs analysis makes it possible to consider in detail the changes in the structure of the surface depending on the energy of the laser pulse. The main structural change is ablation. That occurs near the fibers or on the upper layer of the composite, depending on the energy of the pulse, and at the contact surface with the matrix, the effect of ablation is more significant. An energy of 1 μJ can remove only the outer layer of epoxy, without damaging the fibers. A pulse energy of 3-4 μJ causes the elimination of multilayer fibers, at 5 μJ it already occurs. An increase in pulse energy leads to heterogeneity of the cut area morphological structure. The fibers begin to protrude from the surface as the ablation of the epoxy polymer matrix is greater than the fiber. The distribution of destruction rate between the fiber and the matrix can be controlled by carefully tuning the pulse energy and scan rate [5]. But despite the numerous advantages, there are also disadvantages. The main problem with cutting is thermal damage and HAZ, charring, epoxy matrix destruction and delamination, which can lead to material quality degradation. The laser beam directed at the material also leads to heating of the local surface, which causes the formation of different phases of the material and the formation of a recrystallized layer. In addition, when the beam collides with the beam, a large part of this absorbed energy is transformed into locally distributed thermal energy, which heats the material under the beam to very high temperatures, forming a cut to a certain depth in the form of a cone (taper) [6].

The absorption rate of the IR laser by the polymer matrix is less than 15%. 85% of the energy passes through the polymer matrix and heats the carbon fibers [10]. The energy of the UV laser is almost completely absorbed by the resin matrix. To this end, the UV laser has better cutting potential and the HAZ is larger for the IR laser than for the UV laser.

It is also possible to reduce the harmful effects by means of scanning mode. By increasing power due to high power and fast material removal, a 25% increase in efficiency can be obtained, but processing speeds must also be increased to inhibit thermal effects. The short-pulse laser had the smallest HAZ, while the efficiency was 25% higher.

Freitag [11] optimized the pulse energy and repetition rate of the pulsed laser to reduce the HAZ width and found that high cutting quality could be obtained at high pulse energy and high repetition rate for the same average laser power. Leone [12] found that better cut quality was obtained with multi-channel technology at higher scan speeds, and the HAZ width could be significantly reduced. A continious laser is effectively used, which provides low accuracy but high efficiency [7].

One of the limiting factors of the development trend of laser use is the low absorption capacity of the polymer matrix, which leads to thermal destruction and delamination. To improve it, introducing additives that will serve as an adsorbent of the energy of laser radiation may be considered. Carbon particles were found to significantly reduce defects due to increase of absorption in the matrix material. Optical transparent pigments, such as Fabulase 361 additive also may be used [8].

But the introduction of carbon nanotubes is of greater interest. In [9] the process of introducing multiwall carbon nanotubes to polystyrene matrix is described. The composite was prepared using the extrusion and a ready masterbatch. The results of the introduction of nanotubes for the quality of laser cutting are positive. The nanotubes alignment is also considered as a factor affecting the cutting quality. Oriented carbon nanotubes provide better conditions for cutting results, except for the taper formation, which is less favorable compared to multiwall nanotubes. From the factors of the width of the cut, the influence of the thermal zones, the taper angle, it can be concluded that the general alignment is better for laser cutting than samples without special nanotubes alignment.

CONCLUSIONS

In this review the use of carbon fiber reinforced composites in various industries is considered. Fiber reinforced carbon composites are characterized by high strength, hardness and low specific weight, as well as low thermal expansion. By changing the matrix, unique properties such as resistance to corrosion and aging can be achieved.

However, to ensure the optimal level of processing quality of these composites, it is important to choose appropriate processing methods.

Traditional machining methods have their limitations and prone to problems such as fiber shedding, material separation, resin flaking, poor productivity and tool wear. Laser cutting, on the other hand, is a more attractive method because it is non-contact, has less tool consumption, is more controlled, and allows changing processing parameters with a significant reduction or elimination of thermal effects on the material. However, thermal damage of the matrix can affect the quality of the cut. The use of laser cutting usually helps to reduce thermal effects, but processing parameters such as scan speed, laser power, pulse characteristics and wavelength must be carefully selected. Additionally, the introduction of additives, such as carbon particles or carbon nanotubes, can help improve processing quality by absorbing laser energy and reducing the thermal impact on the material.

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