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Laser Material Processing for Aerospace Applications

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The aeronautic industry is constantly looking for new techniques to save fuel consumption and reduce cost. Utilizing materials with improve strength and reduced density is by far the most efficient way to achieve this goal. New fabrication techniques or a process that reduces the total manufacturing cost is another strategy to reduce the cost of aircraft ownership. The fabrication of aircraft component is labor intense. The techniques that decrease processing time and reduce the use of labor are particularly attractive. In this front, laser material processing has been proved to be competitive, owning to its rapid processing, single-step operation and versatility.

At present, traditional laser systems such as continuous wave (CW) and nanosecond pulsed lasers dominate the aeronautic fabrications [1-4]. CO_2 laser operates at continuous mode with a wavelength of 10.6 μm. This type of laser is the earliest used in aerospace manufacturing. Nd: YAG lasers are primarily of the pulsed type. The wavelength is in the near infrared at 1.06 μm. In recent years, fiber lasers gained much interest [5,6]. This type of laser is produced by excitation doped optical fiber using diode lasers. Among this category of lasers, ytterbium doped fiber is the most cost effective one for high power applications in aerospace manufacturing. Ytterbium fiber lasers operate at wavelength of 1.07 μm.

The powers of these lasers are in the order of few hundreds of watts to few thousands of watts. They are employed for the cutting and fusion welding of alloy and super alloy sheets, turbine engine deep hole drilling, repair of blades for gas turbines aircraft engines, on-the-fly drilling of de-icing panels and heat treatment of surfaces. Marking and engraving on critical components can also be done with laser systems. In these applications, the laser system is integrated with CNC machine and the laser is used as non-contact machining tool. In the conventional manufacturing, tools must be replaced or repaired regularly due to wear. The non-contact nature of laser machining saves manufacturing cost by the complete elimination of tool wear. Another advantage of using lasers as tools is that laser material processing is highly versatile. By tuning laser parameters, multiple tasks: cutting, drilling, welding and cladding and marking critical components all can be carried out with a single machine. With CW lasers and pulsed lasers, cutting and drilling work on the thermal heating mechanism. Material melts and evaporates upon absorbing laser photon energy. This process occurs very fast, usually in the time scale of nanosecond to microsecond. Therefore, laser systems are capable of processing materials at very high rate. In some cases the processing time is limited by the positioning system rather than the laser material processing itself.

The main concern of laser material processing is the burrs that formed by the residue molten material. This usually leaves a poor edge finish and a large heat affected zone, affecting the fatigue life of mechanical parts which is critical for aerospace applications. Secondary operations must be employed to improve the edge condition. The cost of the secondary operation makes laser material processing less attractive. To address this issue, pressured assist gas is used to reduce burr. The usage of assist gas also improves productivity in some applications.

In recent years ultrafast lasers have gained a lot of research interest. There are two types of ultrafast lasers: picoseconds $(1\times10^{-12}\text{ second})$ and femtosecond $(1\times10^{-12}\text{ second})$. The extreme short pulse duration of ultrafast laser provides peak power reaching giga watts. Almost all kinds of materials break down instantaneously under ultrafast laser irradiation. Even hard-to-ablate materials, such as glass, can be machined with ultrafast laser. At the extremely high peak power, material breakdown is induced by direct fragmentation or evaporate rather than the thermal heating mechanism that dominates the conventional laser material processing. Therefore, defects induced by thermal heating, such as burr and heat affected zone, is minimized, therefore, superior finishing quality. Currently, ultrafast lasers are limited to micromachining applications due to the low average output power [7]. The typical output power is about 10-20 W. Picoseconds lasers are used more commonly than femtosecond lasers for material processing because it is relatively easier to achieve high power with picoseconds pulses. Also, high-powdered picoseconds lasers are more economical compared to femtosecond lasers.

The emerging of ultrafast laser material processing in the aeronautic industry is driven by two factors. First, the introduction of new materials and new designs requires new manufacturing techniques [7]. Secondly, the output power of ultrafast laser increases rapidly with the advancement of laser technology, making them more and more viable for macroscale material processing. There are a few commercial ultrafast laser systems that provide output power higher than 50 watt. The Hyper Rapid 50, a picoseconds laser from Lumera Laser, gives 50 watt at a wavelength of 1064 nm and 1000 kHz repetition rate. With all-fiber technique, it is possible to build picoseconds laser with maximum power above 150 watt [8]. Applied Energertics produces custom-build femtosecond lasers (~100 fs) that is capable of over 100 watts [9]. These laser systems are still new on the market. There is no report on material machining with these lasers. The power of these ultrafast laser systems is still quit low, compared to output power of conventional laser systems used for aerospace manufacturing. However, materials breakdown at much lower threshold (the minimum energy required to induce material breakdown) under ultrafast laser pulses. It is not unreasonable to expect that ultrafast lasers might be able to perform the same material processing with much lower output power.

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