3D Printing of Thermoplastics with Higher Strength Using SWIR-Supercontinuum Laser

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Abstract: Hydrocarbon based thermoplastics used in 3D printing can be sintered using a supercontinuum laser operating between 2-2.5μm. We sinter 11 different materials and fabricate rods with strengths up to 5x of that from CO_2 lasers.

OCIS codes: (350.3390) Laser Materials Processing; (140.3510) Lasers, Fiber

We demonstrate that a short-wave infrared super-continuum (SWIR-SC) laser sinters a wide variety of thermoplastics used in 3D printing since the 2-2.5 micron wavelength range corresponds to the combinational bands in most hydrocarbon based materials. Furthermore, we show that rods created using our SWIR-SC laser have a 1.5-5x larger flexural modulus than those made using a CO_2 laser. SWIR-SC lasers can increase the number of viable materials for laser sintering and improve the strength of existing materials by creating a more uniform heat profile on the surface of a powder bed, thus serving as a viable light source for 3D printing of thermoplastics.

Current challenges in additive manufacturing of plastics include that different light sources are required for different plastics, and the 3D printed structures lack laminar strength due to the layer-by-layer manufacturing. For example, CO_2 lasers are used to sinter nylon materials, while UV light is used for polyethylene. Also inferior mechanical properties of sintered Polyether ether ketone (PEEK), high-density polyethylene (HDPE), and polypropylene are described in [1,2] and can be attributed to porous structures resulting from poor layer adhesion.

Common to almost all of the thermoplastics used in 3D printing is that they contain hydrocarbons, so they have SWIR absorption bands from their C-H combinational bands. Figure 1 shows this range of absorption peaks from 2.15-2.5μm in Nylon 12, PEEK, and HDPE, which is exemplary of the C-H combinational band in thermoplastics. The range of penetration depths associated with these absorptions allow a laser to more uniformly heat sintering zones, thus creating better adhesion between layers and leading to increased laminar strength in sintered structures.

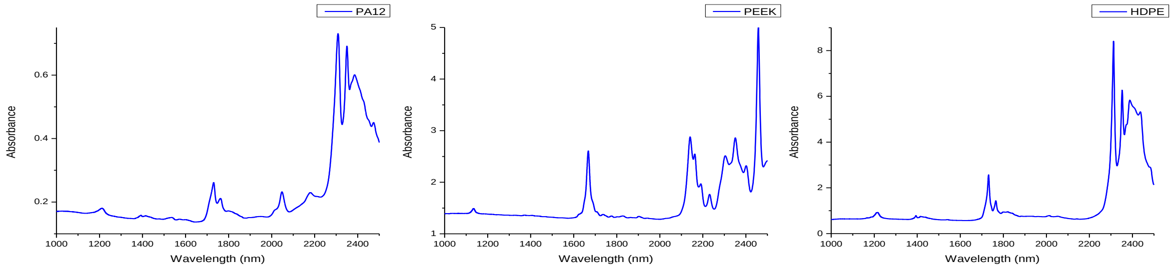


Fig.1. Representative absorption spectra depicting C-H Combinational bands in the 2.15-2.5μm range and first overtone near 1.7μm

The set-up for testing different photopolymers uses a variety of lasers whose light are collimated then focused onto a powder bed, as shown in Fig. 3. To benchmark the performance for different cases, four light sources are used for plastic machining. First, we use an all fiber based SWIR-SC laser utilizing a seed laser, two stage amplification, and a fiber for nonlinear spectral broadening to output 25W in the 2-2.5μm wavelength range. Further details are provided in [4]. Next, a bandpass filter is placed in front of the SWIR output to give the Filtered SC source with a 2320-2380nm wavelength range. Third, we use a 30W, 10.6μm CO_2 laser (Diamond C-30, Coherent) to benchmark our results. Finally, we use a 12W, 1685nm Diode laser (BriteLase 6017, QPC Lasers) to inspect the first overtone absorption peak near 1700nm (Fig. 1). A wide array of thermoplastics are sintered with the SWIR-SC laser. We target Nylon 11, Nylon 12, Polystyrene, Polycaprolactone (PCL), Poly(glycerol-dodecanoate), Polyvinyl alcohol (PVA), PEEK, HDPE, Low Density Polyethylene, Polylactic acid, and Poly-l-lactic acid.

Rods are created from Nylon11, Nylon 12, PEEK, PVA, and PCL powder using all four light sources and tested for flexural properties. The rods are sintered by placing each powder bed on a computer controlled X-Y translational stage (Fig. 3). To achieve a maximum rod density without thermal degradation as described in [3], the laser power for each source is tuned to just below the damage threshold at a translational speed of 1064μm/sec.

Three sets of 10 rods are made from each powder/light source combination and 5 rods from each set are chosen randomly for testing. The flexural modulus is calculated from the results of 3pt bend tests run on an MTS machine.

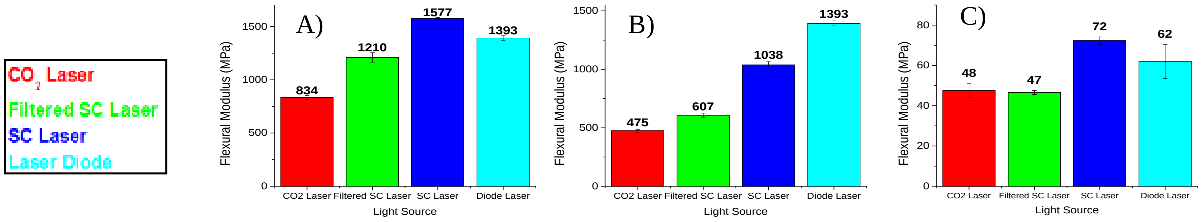
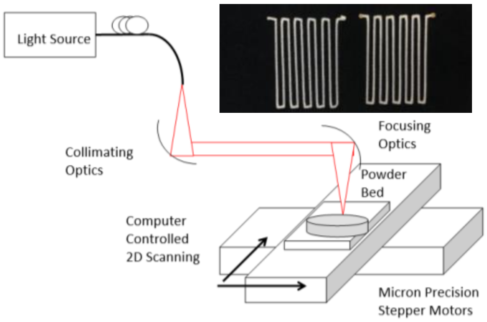


Figure 2. Flexural moduli of rods created from A) Nylon 12 B) Nylon 11 and C) PCL powders

We compare the flexural moduli of rods created from the 5 powders. Figure 2 depicts our results from A) Nylon 12, B) Nylon 11, and C) PCL rods. From left to right, the columns in each graph represent the average flexural moduli of rods created with the CO_2 laser, the filtered SC laser, the SWIR SC laser, and, finally, the diode laser. In all samples we see that rods created with the SWIR SC laser have a 1.5-5x larger flexural modulus than rods created with the CO_2 laser. Furthermore, filtered SC sintered rods consistently exhibit flexural moduli between CO_2 and SC sintered flexural moduli.



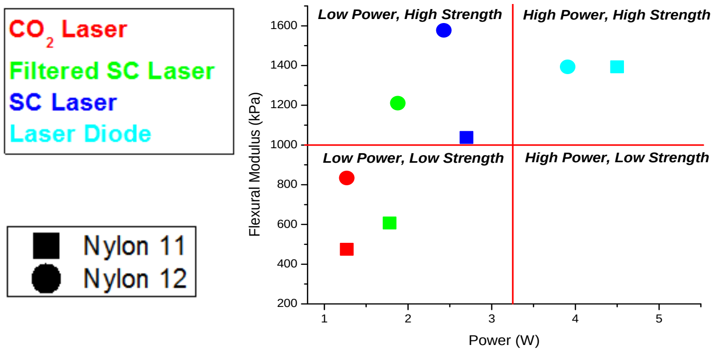


Fig 3. Experimental setup and rods made in Nylon 11 and Nylon 12

Fig 4. Flexural Modulus vs Sintering Laser Power in Nylons.

To elucidate the trade-offs between power and strength, Fig. 4 plots the flexural modulus versus the power used for sintering in Nylon 11 and Nylon 12. The powers are chosen to be just below the power at which thermal degradation would begin to occur given our sintering parameters. In Fig. 4 we see that the CO_2 laser requires the lowest power but produces the weakest rods, while the diode laser produces strong structures with a much higher power requirement. SWIR-SC rods require moderate power but at the same time have a high flexural modulus. Depending on your system requirements, you can use a different laser for different tasks. If minimal incident power is preferable choose a CO_2 laser. If power is less of a concern and high strength is needed, it is worthwhile to choose a SWIR or diode laser for sintering.

Our results show that the SWIR-SC is a viable source for thermoplastic 3D printing because it can sinter thermoplastics and create stronger materials by combining the characteristics seen in the CO_2 and 1685nm diode lasers. All 11 materials tested can be sintered via their absorptions in the combinational band (c.f. Fig. 1). We believe that the increased strength in SC samples is due to a range of penetration depths within this band. The CO_2 laser's light at 10.6μm is calculated to penetrate ~100μm in Nylons, whereas SC light penetrates 2-6x deeper. High absorption wavelengths, such as 10.6μm, promote efficient sintering. On the other hand, overtone band wavelengths near 1685nm provide deep penetration and uniform heating. The SWIR-SC laser combines both these features to produce parts with high strength at a low required power as shown in Fig.4.

In summary, we have sintered 11 different thermoplastics and found that up to a five-fold increase in flexural modulus can be achieved using a SWIR-SC laser over a CO_2 laser. Thus, our data supports that the SWIR-SC laser can be a viable light source for the laser sintering of thermoplastics. Furthermore, because the SWIR-SC laser is similar to fiber lasers used in metal powder sintering, the SWIR-SC fiber laser should share similar reliability traits.

References

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