Scaled Additive Manufacturing of Industrially Relevant Polymers with Scanning Multi-DLP® Adaptive LightBars™: Implicit Data Representations and Synthetic Deconvolution

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We are commercializing the world's largest, fastest additive manufacturing printers based on multiple DLP® light engines, so-called Adaptive LightBars™, combining market-leading advances in materials, hardware and software.

Adaptive3D, a wholly owned subsidiary of Desktop Metal, Inc. (NYSE: DM), is a materials manufacturing company that leads the industry in offering high-strength, high-performance, tough elastomeric resins for production-grade 3D printing. As industry forerunners, we provide key insights and expertise in creating optimized, micro-architected structures that use significantly less material than market alternatives to achieve better load-transfer capabilities for end-use applications. Desktop Metal works with Fortune 1000 companies across six marquee industry segments: *Industrial & Electrical*, *Transportation*, *Energy*, *Consumer*, *Medical* and *Defense* to develop and deploy solutions for superior materials and part performance.

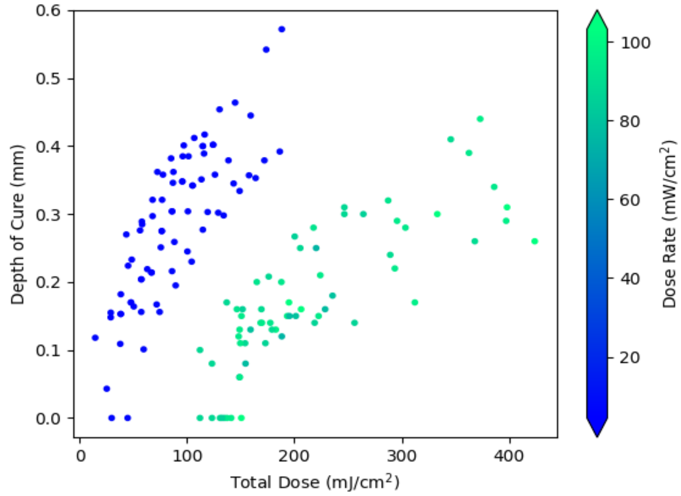

Figure 1. *Data points represent the resulting cure profile of* Elastic ToughRubber 90 (ETR 90) White *resins cured under different doses and dose rates. ETR 90 has a toughness of >15 MJ/m^3, a tear strength of 38 kN/m, elongation of 190% and 12 MPa stress during quasi-static loading at 25°C. ETR 90 has a wide thermal use window between -60°C and 150°C. In the past, it has been prohibitively difficult to directly print high-performance photoelastomers.*

For additive manufacturing to effectively compete with current industrial manufacturing methods, large scale additive manufacturing tools must be envisioned and realized. The most cost-effective way to pattern complexity into additively manufactured parts is through the use of light, often called stereolithography. Large vat laser systems are slow (requiring long raster times) and large vat DLP systems often suffer from low power density, enlarged pixels (low resolution) and stitching issues (where projection boundaries resolve into undesirable lines within a part). Furthermore, as DLP systems age, individual pixels begin to wear and die, leading to failed prints and higher reject rates. As manufacturing relies on reproducibility as the mainstay of its existence, DLP based additive manufacturing must solve this problem to compete with and surpass entrenched polymer manufacturing technologies such as injection molding, extrusion, blister packaging, blow molding and vacuum-assisted resin transfer molding.

Adaptive LightBars are moving, scrolling multi-DLP light engine tools that cure individual voxels with partial dose contributions from thousands of different mirrors, rastering over that voxel at a prescribed rate. This amortized cure mitigates the issues of aging and dying pixels as the cure dose is delivered as a partial dose from thousands of individual mirrors leading to Gaussian dose distributions. Further, as the LightBar is moving and scrolling, issues of stitching are mitigated through intelligent multi-projector overlap. The LightBar tool demonstrates scroll at speeds up to 1 meter per second while delivering 10× better energy density (>80 mW/cm^2) than any other large commercial DLP printer on the market, enabling high-volume, high-resolution and high-throughput mass manufacturing of photopolymers. Adaptive LightBar systems will enable the manufacture of tens of millions of nasal swabs, millions of earpieces, hundreds of thousands of gaskets and O-rings, and tens of thousands of midsoles annually per tool and will also support customers across a broad range of other industries.

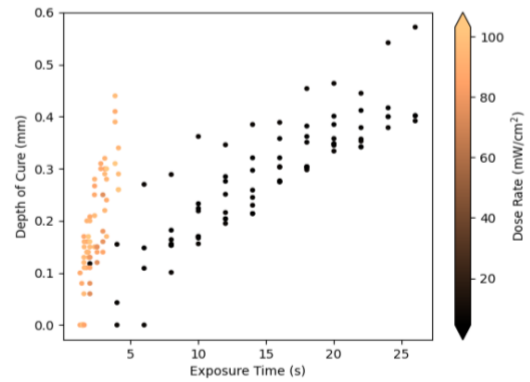

Figure 2. *Per voxel cure speeds increase substantially with increasing dose rate in performance elastomers.*

Advances in machine capacity have also necessitated advances in software. To achieve increased complexity (*e.g.* 50 µm resolution across meter plus parts), current *.STL* and *.DMF* implementations are inadequate to drive large vat printers. Files often exceed many terabytes in size and do not facilitate printing high-resolution parts at industrial scales. We describe a versatile, extensible, implicit data representation which can be readily compressed and decompressed and enables real-time modification and scaling in its compressed state using modern algorithmic approaches. LightBar firmware parses these data structures quickly and efficiently, streaming data into DMD chips at up to 10 kHz in “movie-like” layers that drive individual mirrors as they scan rapidly over the surface of a build plate. Current industry standard inputs are readily printable in this framework and can also be seamlessly converted into our richer data formats often enabling topological adjustments to achieve superior strength-to-weight ratio of resulting parts. By tuning the duty cycle, scanning speed, power density and energy density, we enable the mass-manufacturing of complex meso-architected parts at large scales with fine resolution, excellent surface finish and high throughput. Our proprietary algorithms and GPU-accelerated graphics processing enable data transfer that amortizes dose across thousands of individual mirrors to improve reliability and enable redundancy at scale. By tuning the parameters related to the cure kinetics of polymer resins, novel dose and dose rate phenomena have emerged from the first versions of LightBar tools as they manufacture parts made using Adaptive3D’s commercially available chemistries, such as ETR 90.

In this plenary talk, we will highlight the resulting ‘Depth of Cure’ given a specified input energy into the system (Total Dose) and how fast that energy is delivered (Dose Rate) onto the photoresin. There is a clear dichotomy between the cure profile of *ETR 90 White* when cured using a low dose rate (blue) and high dose rate (teal) (**Figure 1**). Despite exposing the resin to the same total amount of total energy, higher dose rates lead to lower depths of cure, critical for achieving finer resolution. **Figure 2** demonstrates the total exposure time scales indirectly with LightBar size enabling rapid curing of individual voxels in a few seconds at higher dose rates of 80 mW/cm^2. This talk will explore the resulting scaling laws from these dose and dose rate studies and showcase a variety of applications and achievable throughputs that far exceed current industry standard solutions in the additive manufacturing market. Adaptive3D has validated that distributing dose across thousands of dosing events on its LightBar systems enables a new paradigm in scaled DLP-based additive manufacturing. When printing high performance materials, such as ETR 90, we can optimize load-deflection curves across complex micro-architectures. We explain the effects of exposure and irradiance time on the cure speed of various photoresins and demonstrate the effects of varying total dose and dose rate on resulting thermomechanical properties. We will demonstrate case studies from several high-volume markets that benefit from LightBars and high-performance photoresins.