UNIT 3

VAT POLYMERIZATION AND DIRECTED ENERGY DEPOSITION

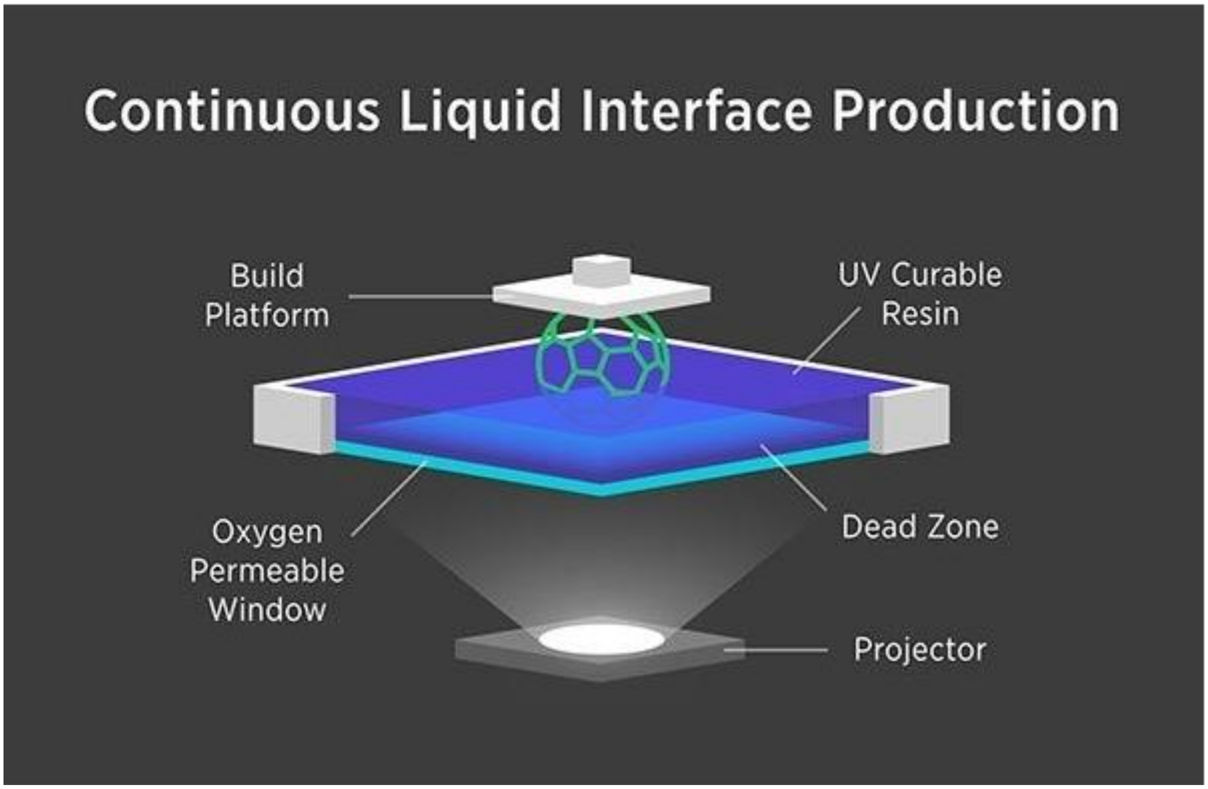
3.3 CONTINUOUS LIQUID INTERFACE PRODUCTION (CLIP) and LASER ENGINEERED NET SHAPING (LENS)

3.3.1 Introduction to CLIP

The purpose of this paper is to understand and research literature on the “continuous liquid interface production (CLIP)” of 3D objects to address the current challenges. This proprietary technology was originally owned by EiPi Systems but is now being developed by Carbon 3D. Unlike conventional rapid prototyping of printing layer-by-layer to print 3D objects, CLIP is achieved with an oxygen-permeable window made of proprietary glass membrane and the ultraviolet image projection plane below it, which allows the continuous liquid interface to produce 3D objects where photo-polymerization is restricted between the window and the polymerizing part. This process eliminates the time requirement in between the layers resulting in the faster production of 3D objects with a resolution less than 100 microns. It is a known factor that the “supports” play a vital role in any liquid based 3D printing techniques and this does not change in CLIP. In addition to the parameters of support structure like shape, size, strength, ease of removability, surface finish after removal of supports etc, CLIP needs to deal with different types of materials. The support structure needs to be designed according to the respective material’s properties. There are two broad categories of the materials available from Carbon 3D, prototyping resins, and engineering resins. While the prototyping resin is used for the cosmetic models and the engineering resins are used for the practical applications. There are 6 types of engineering resins developed for the end user; of these, EPU and CE are more challenging to work with. EPU parts needs more supports and careful handling till the completion of post processing as the material is soft. CE parts are fragile and needs more systematic handling to complete the successful production. Although printing parts of EPU and CE is more time consuming when compared to the normal CLIP process, they are worth for their unmatched industrial applications. None of the existing 3D printing technologies offers this quality. The support structure, orientation and pot life are the influencing parameters for all resins. In this study, it is statistically proven that by optimizing the part orientation with respect to the slicing of each layer and customized supports; parts are built way better than before. The part orientation is optimized by ensuring each layer is supporting the subsequent layer and minimizing the islands. It is noticed that the results are always better by tilting the part 5 to 10 degrees in both X and Y axis in the build setup and this applies for most of the straight geometrical parts. For parts of specific geometry which can create a vacuum while pulling up the part needs to be oriented in a different way or create a re-closable air passage that can prevent the vacuum being created.

3.3.2 How does CLIP work?

This section will explore the workings of a CLIP™ printer to explain its differences over other vat polymerization technologies. Figure 2 shows the important components of CLIP™/DLS printers and their general arrangement, and we will use Figure to briefly explain the functionality of each part, starting from the bottom up.



Light Engine/Projector

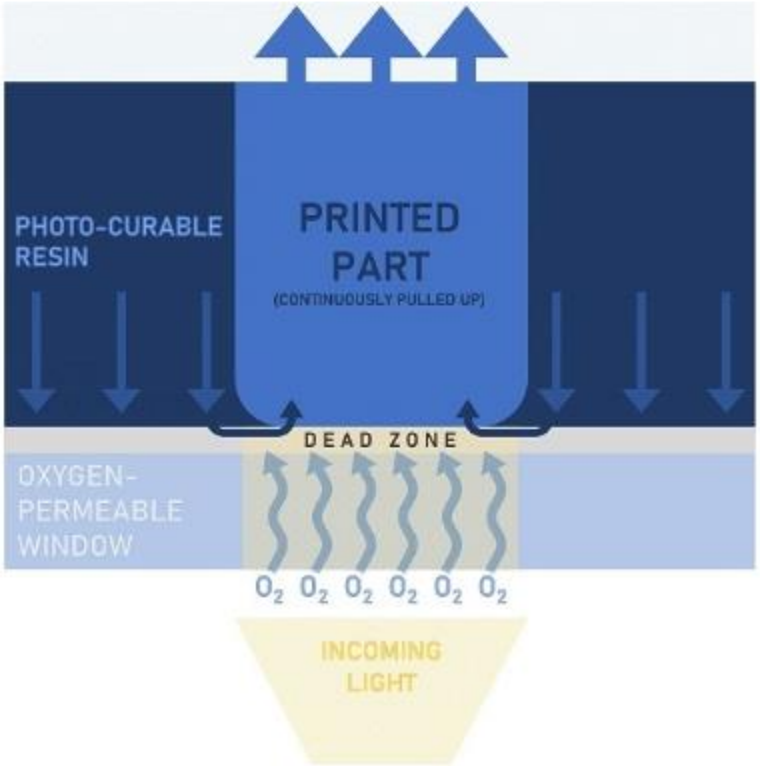
The projector, also known as the light engine, provides a curing light source for the print and is situated underneath the resin vat. The light engine projects a sequence of UV images through the vat and onto the build platform. Note that these images are not the discrete layers found in SLA/DLP light sources, but a changing sequence of cross-sectional images, leading to a layer-less print.

These light engines are like those found in DLP designs; they have a set resolution, are digitally projected, and cast a layer's worth of light at a given time. The difference between CLIP™ and DLP is that, though they have comparable resolutions, the CLIP™ process smoothly blurs the layers together and eliminates the so-called oxalated effect that is typically seen in DLP prints. Not only does this lead to excellent out-of-print finishes, but also faster build times and less post-processing work.

Photopolymer Vat & Oxygen-Permeable Window

The photopolymer vat is the vessel where the UV-cured resin is held, and where the magic of CLIP™ printing takes place. Below, Figure shows a close-up of the interface between the resin (dark blue) and the photopolymer vat (sky blue):

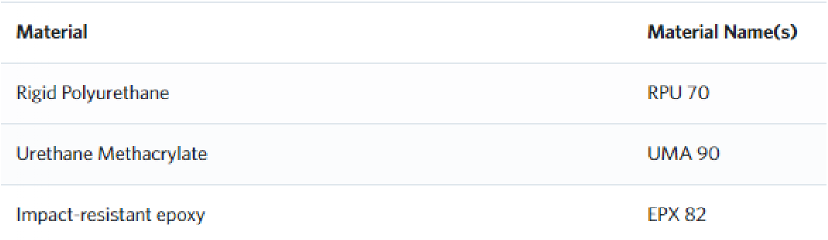
The floor of the photopolymer vat is composed of a transparent oxygen-permeable window. This window allows both incoming light and oxygen to pass through to the resin. The oxygenated resin will not cure in the presence of light and forms a so-called "dead zone" of liquid resin that remains under the printed part.



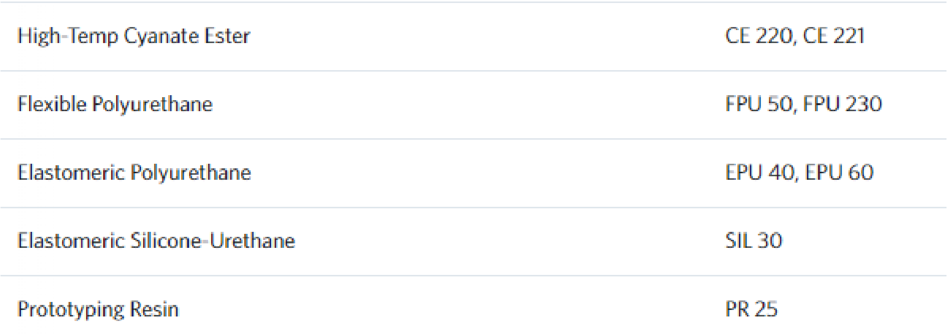
This permeable membrane is the key component of CLIP™ technology; as the part is slowly raised out of the vat, the liquid dead zone allows the resin to flow under the part at a constant rate while preventing resin from curing on the window. The incoming light then cures the resin outside of the dead zone as the part is pulled up, creating the 3D print. Carbon 3D will not exactly divulge the chemistry of how this all works, but the result is a continually growing 3D printed part with no peeling or stopping necessary.

UV-Curable Resin

CLIP printers use thermosetting resin – or a polymeric liquid that solidifies in the presence of UV light. Though CLIP™ printers use similar materials to SLA/DLP designs, their unique printing process creates parts with enhanced surface finishes and mechanical properties and allows for more interesting materials. Below is a table that provides some examples of resins currently used in a CLIP/DLS printer:



Material	Material Name(s)
Rigid Polyurethane	RPU 70
Urethane Methacrylate	UMA 90
Impact-resistant epoxy	EPX 82



High-Temp Cyanate Ester	CE 220, CE 221
Flexible Polyurethane	FPU 50, FPU 230
Elastomeric Polyurethane	EPU 40, EPU 60
Elastomeric Silicone-Urethane	SIL 30
Prototyping Resin	PR 25

Many resins require a mixture of two separate parts. Operators must calculate exactly how much resin they need, how much of each part they need, and how long their working time is before the resin becomes unusable. There is no re-using resin once it is mixed, so it is important to get the timing and ratios right before beginning the print.

The part is not yet finished after it has solidified. After the print, it must be cleaned of excess resin and any supports must be removed. Depending upon the material, a final thermal-post cure is needed to fully harden the part. This involves placing the part in an oven for an extended period (4-13 hours), where a secondary chemical reaction occurs, strengthening the part further.

Build Platform & Elevator

The build platform is the working space to which the resin adheres, and it is mounted to an elevator that controls the vertical (z-axis) movement of the part. The build platform starts partly submerged in the resin vat and is raised up via the elevator. The elevator is precisely controlled by the printer to keep resin flowing underneath the part, and is responsible for the "growing" effect of this 3D printer. These components are tied into an array of sensors and microprocessors to ensure the print is accurate and maintains structural integrity.

3.3.3 Advantages & Limitations of CLIP

Emerging CLIP technology is an upgrade from more conventional 3D printers and is an incredibly promising additive manufacturing tool. This section will detail the advantages and disadvantages of CLIP technology.

The advantages of CLIP printing are as follows:

- CLIP prints have the accuracy and the surface quality of DLP/SLA prints but are completed 100 times faster.
- CLIP prints are layer-less, enhancing their surface finish to be comparable to injection-molded parts.
- Parts are watertight, fully isotropic (have strength in any orientation), and have increased strength over SLA/DLP prints.
- Parts can be used for functional prototyping and even for full production runs.
- The material choices for CLIP/DLS printers are widely varied and unique to many other printer types.

The limitations of CLIP printing are as follows:

- Carbon3D's line of CLIP/DLS printers can only be rented, and the printers themselves are very expensive to rent and train personnel on (upfront cost is $64,000+). The resin is also expensive ($99-$399 for each container).
- CLIP is still an emerging technology, so support is difficult to find and there are few options (if any) to choose from.
- CLIP/DLS is still under active patent, so alternatives will not be available for a long time or until the rights are sold. Access to Carbon's rental program is also limited.
- While creating amazing, production-quality parts, investment in CLIP technology can be harder to justify at present given so many affordable 3D printers provide good results at lower price points.

3.3.4 Applications of CLIP 3D Printing

CLIP/DLS printers are used in applications that require mass customization and fast lead times. Such a versatile machine has nearly infinite applications, but the brief list below shows off some of its most well-known uses:

- Medical equipment/tools/impressions
- Footwear midsoles & athletic equipment
- Automotive parts
- Prototyping
- An alternative process to injection molding
- End-use functional parts & direct digital manufacturing

3.3.5 Introduction to Laser Engineered Net Shaping (LENS)

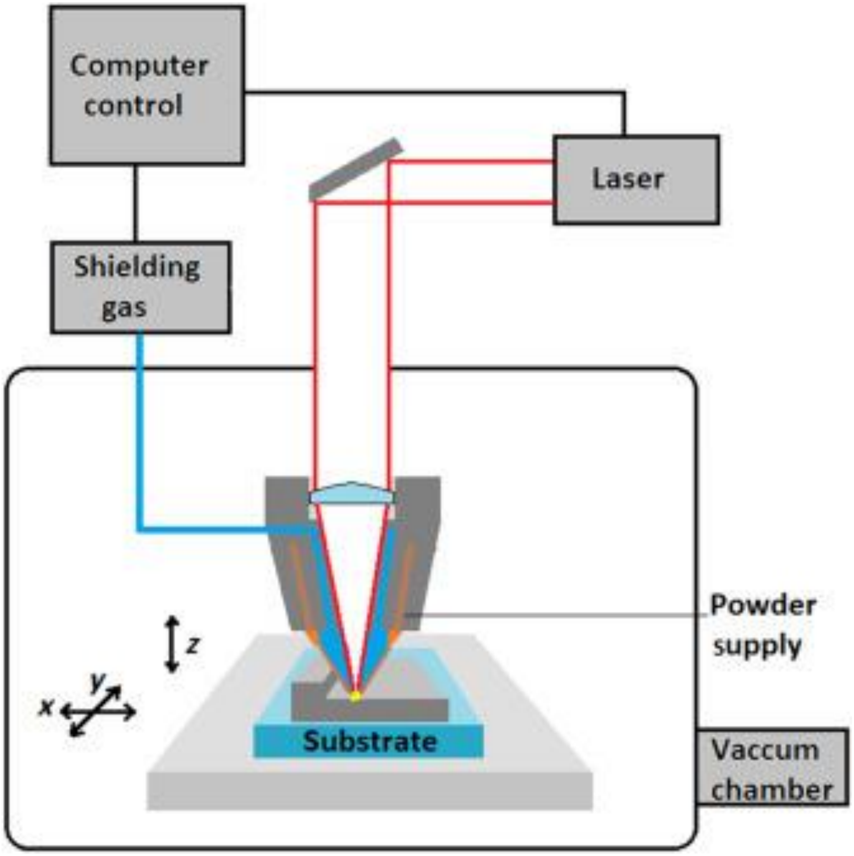
Laser powder forming, also known by the proprietary name (laser engineered net shaping) is an additive manufacturing technology developed for fabricating metal parts directly from a computer-aided design (CAD) solid model by using a metal powder injected into a molten pool created by a focused, high-powered laser beam. This technique is also equivalent to several trademarked techniques that have the monikers direct metal deposition (DMD), and laser consolidation (LC). Compared to processes that use powder beds, such as selective laser melting (SLM) objects created with this technology can be substantially larger, even up to several feet long.

Method

A high power laser is used to melt metal powder supplied coaxially to the focus of the laser beam through a deposition head. The laser beam typically travels through the center of the head and is focused to a small spot by one or more lenses. The X-Y table is moved in raster fashion to fabricate each layer of the object. The head is moved up vertically after each layer is completed.

Metal powders are delivered and distributed around the circumference of the head either by gravity, or by using a pressurized carrier gas. An inert shroud gas is often used to shield the melt pool from atmospheric oxygen for better control of properties, and to promote layer to layer adhesion by providing better surface wetting.

Technique



This process is similar to other 3D fabrication technologies in its approach in that it forms a solid component by the layer additive method. The LENS process can go from metal and metal oxide powder to metal parts, in many cases without any secondary operations. LENS is similar to selective laser sintering, but the metal powder is applied only where material is being added to the part at that moment. It can produce parts in a wide range of alloys, including titanium, stainless steel, aluminum, and other specialty materials; as well as composite and functionally graded materials. Primary applications for LENS technology include repair and overhaul, rapid prototyping, rapid manufacturing, and limited-run manufacturing for aerospace, defense, and medical markets. Microscopy studies show the LENS parts to be fully dense with no compositional degradation. Mechanical testing reveals outstanding as-fabricated mechanical properties.

The process can also make "near" net shape parts when it is not possible to make an item to exact specifications. In these cases post production process like light machining, surface finishing, or heat treatment may be applied to achieve end compliance. It is used as finishing operations.