Technical

Simulation solutions for polymer additive manufacturing

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TECHNICAL NOTEBOOK
Edited by John Dick

Executive summary

Additive manufacturing, by definition, is a process of joining materials to make objects from 3D model data, usually layer upon layer. Compared with subtractive manufacturing, in which the unwanted material is removed, instead, materials are added continuously layer by layer in the additive manufacturing process.

This unique feature brings about a lot of merits to AM, such as easy manufacturing of complex geometrical models, reduction of raw material waste and efficient time-to-market. Because of such attractive advantages, a variety of industries such as automotive, aerospace, sports and health care/life sciences are increasingly looking to exploit its benefits. Polymeric materials constitute approximately 50 percent of the total market share, of which rigid polymers take up the majority of the market share.

On the other hand, commercially available elastomeric or rubber-like materials are not so plentiful. However, with the advancement of new and innovative AM techniques, the fabrication of parts using elastomeric materials will be more prevalent in the market.

The adoption of AM is being aided further by the rapid advance in simulation technology in terms of multiphysics optimization and predictive analytics. With design no longer constrained by subtractive manufacturing techniques, a mechanical designer can easily determine product requirements such as:

• Functional objective of the part;
• Part design with the same functional characteristics but using less material; and
• Cost-savings through utilization of optimized additive manufactured parts.

Process simulation solutions allow us to print these unique designs successfully by providing us with detailed analytics that helps us predict residual stresses and potential failures as well as optimize the printing process parameters so that each part can be printed right the first time.

An elastomer, interchangeably called rubber, is a polymer with viscoelasticity generally with low Young's modulus and high failure strain compared with other materials. Elastomers can be grouped into two categories: Thermoset elastomers and thermoplastic elastomers.

There are a few techniques that can be used to fabricate such materials. The following are some of the techniques utilized for elastomeric polymer additive manufacturing (AM), also known as 3D printing.

1. Selective laser sintering (SLS) (**Fig. 1 (a)**): A high-power laser is employed to fuse small particles by scanning cross-sections generated from a 3D digital file. The printing bed filled with powder is lowered down stepwise and a new layer of powder is then spread over the whole bed. The laser continuously fuses the particles until the whole model is completed.

2. Fused Deposition Modeling (FDM): This technique is widely prevalent because of its affordability, ease of operation, and desktop-style design. **Fig. 1 (b)** illustrates this process, in which nozzles deposit semi-molten materials onto the cross-section area layer by layer and the filaments are fused together upon deposition. The thermoplastic elastomer filament materials can be employed to produce rubber-like products.

3. Polyjet Printing: This process is displayed in **Fig. 1. (c)**, in which the droplets of curable liquid photopolymer are deposited from the print head onto a build tray in ultra-thin layers and UV light is used to cure the deposited layers immediately.

4. Continuous Liquid Interface Production (CLIP): The method is detailed in **Fig. 1 (d)**. In this technique, UV images are fed into the system using a digital light projector via an oxygen permeable UV transparent screen. The printed object is drawn from a pool of UV curable resin continuously.

Elastomeric materials are specially formulated to produce good durability and stability, chemical and heat resistance, tear/abrasion resistance, and shock absorption along with the capability of withstanding repeated flexing and bending.

For example, the photopolymers used in the Polyjet technique can create products with different levels of hardness, elongation and tear resistance. These properties make them useful in many applications, including knobs, gaskets, grips, seals, fittings, hoses, pulls, handles, footwear and others. They can be widely applied to such industries as automotive, aerospace, footwear, sports goods, medical devices, soft robotics and consumer electronics and so on.

Fig. 2 presents a few elastomeric products manufactured through 3D printing: (a) hose; (b) tire; (c) sports shoes; (d) hearing aids; (e) soft robotics; and (f) wearable watch band.

As discussed, AM can deliver good business benefits that cannot be surpassed by conventional manufacturing processes. However, there exists a gap between "as-designed part" and "as-manufactured part" that arises from various build parameters such as transient heat input, building orientation, support structures, filling parameters, and lay-by-layer deposition path. These factors can lead to residual stresses, part distortion, anisotropic material properties, and even functionality failure that needs to be avoided as best as we can.

So how do we maximize the benefits without compromising our products? What technology and software tools should we choose to manufacture the rubber products and improve the part fidelity?

Solutions for the AM process

Additive manufacturing of elastomeric products is evolving from rapid prototyping to industrial production. All the participants in this revolutionary change, for example, 3D printer manufacturers, material suppliers, and end users need a good virtual simulation tool to bring the additive manufacturing performance and efficiency to the next level required by the industry.

The 3DExperience-brand platform provided by Dassault Systemes can give the full power to exploit and understand various additive manufacturing processes. The platform supports a complete end-to-end solution with integrated simulation tools to help advance and improve the manufacturing process.

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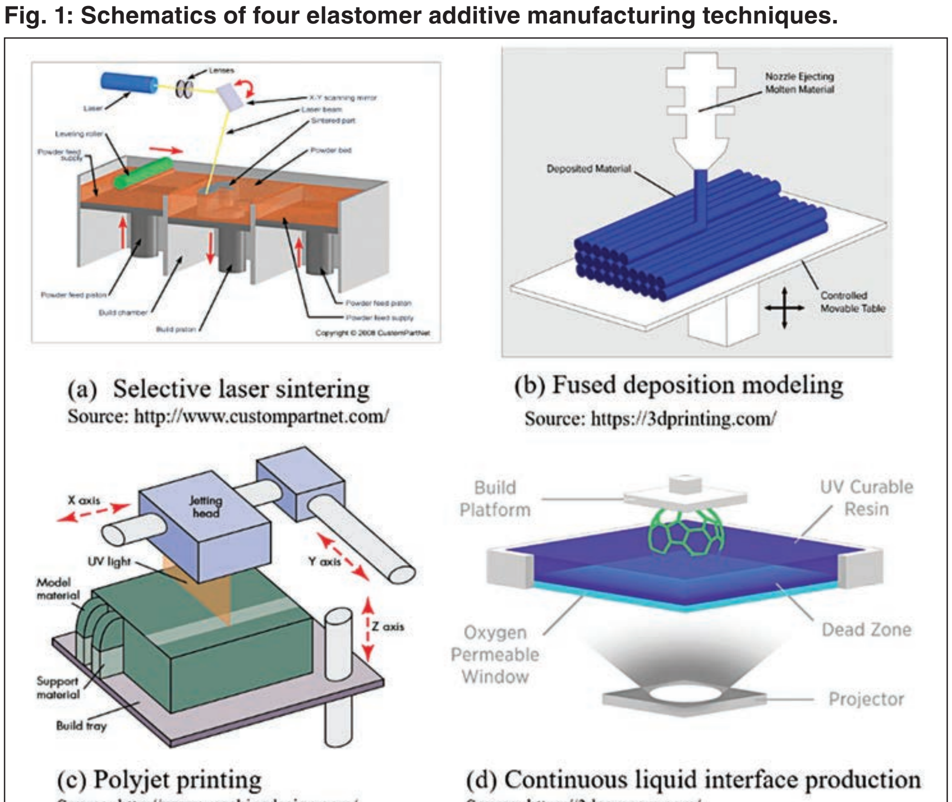
Fig. 1: Schematics of four elastomer additive manufacturing techniques.



(a) Selective laser sintering
Source: http://www.custompartnet.com/

(b) Fused deposition modeling
Source: https://3dprinting.com/

(c) Polyjet printing
Source: http://www.machinedesign.com/

(d) Continuous liquid interface production
Source: https://3dcompare.com/

Fig. 2: 3D printed rubber products.

(a) Hoses
Source: http://www.rapidmade.com/

(b) Tires
Source: https://www.javelin-tech.com/3d/

(c) Footwear
Source: https://www.3ders.org/

(d) Hearing aids
Source: https://envisiontec.com/

(e) Soft robotics
Source: https://disruptionhub.com/

(f) Wearable watch
Source: https://www.lulzbot.com/

The authors

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Arindam Chakraborty is a managing partner and the director of advanced engineering at Virtual Integrated Analytics Solutions, which provides finite element analysis and computational fluid dynamics simulation-based software, training and consulting services.

He has a doctorate in mechanical engineering from the University of Iowa and has more than 10 years of experience in solid mechanics and design, non-linear FEA, fatigue and fracture mechanics, reliability analysis and composite structures.

Chakraborty currently is actively involved with simulation solutions for additive manufacturing process (metals and plastics). He is engaged with Pressure Vessels and Piping conference committees, chairs conference sessions, is involved with ASME and API code committees, and has extensive journal and conference publications experience.

Ellie Vineyard received her doctorate in mechanical engineering from Southern Methodist University in 2017. Her doctoral dissertation topic was mechanical metamaterial design and analysis in which metamaterials with a negative Poisson's ratio and a negative coefficient of thermal expansion has been designed through the heuristic approach and topology optimization.

She has a strong interest in computer-aided design/engineering/manufacturing, and is passionate about using advanced manufacturing and virtual engineering to accelerate product development cycle. She was a summer intern at VIAS, working on additive manufacturing simulation using Abaqus.

TPE production moving from Asia to North America

By Frank Esposito
Plastics News

FAIRLAWN, Ohio—The global thermoplastic elastomer market is at a change point in 2018, with the supply chain shifting from Asia and Europe to North America, according to industry consultant Robert Eller.

Eller

"We're seeing a reverse flow of globalization," Eller said at TPE Topcon, an industry conference hosted by the Society of Plastics Engineers in Fairlawn. "Companies like Black & Decker are finding good TPE compounders in China and other parts of Asia, and then those compounders are setting up operations in North America."

Eller, president of Robert Eller Associates L.L.C. in Akron, added that recent tariff disputes between the U.S. and China will further encourage Asian TPE compounders to start producing their materials in the U.S.

Chinese compounders Kingfa Science & Technology and Polymax Elastomer Technology Co. Ltd. are Asian firms that have added U.S. production in recent years. Kingfa now has operations in Canton Township, Mich., and Polymax has a production site in Waukegan, Ill.

Despite this move toward North America, Eller said the Asia-Pacific region still accounts for half of global TPE demand. The region continues to have a production cost advantage, Eller said, although recent overcapacity has led to lower prices and some commodity-like behavior.

He added that although the global TPE market is maturing, there are still opportunities for advances in automotive and other key markets.

"A car is basically becoming a box of electronics with devices that connect with other cars," Eller said. "That's making opportunities for smart functions for TPEs."

Autonomous vehicles are "creating a path for smart TPEs" to be used in signaling, lighting, sensing and on "smart surfaces," Eller said. Although the TPE market often has used "dumb filler," he said there are now opportunities for TPE makers to tailor fillers at nano-scale.

TPEs also are being used more in auto window encapsulations, where olefinic TPEs are competing with polyvinyl chloride and polyurethane. Another impressive recent development, according to Eller, was Kraton's use of its SEBS-type styrenic block copolymers in an injection molded soft skin for auto applications.

Looking ahead, Eller said he believes that inter-TPE competition will continue and that commoditizing will keep driving prices down. TPE makers "have to figure out how to get out of the commodity track," he added.

Specialty TPEs will continue to gain market share, especially in areas where there's synergy between TPEs and engineering thermoplastics, Eller said, adding that smart TPEs "will allow TPEs to enter a higher-margin space."

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There are many key areas where simulation can play an important role in exploiting the available AM techniques to the full potential, such as

- Generating a functional design;
- Creating lattice structures;
- Calibrating the build material;
- Optimizing the manufacturing process; and
- In-service performance analysis.

On this platform, modeling, simulation and optimization can be unified in a single environment in the function-driven generative designer role, which can facilitate the designer to explore unattainable function-driven conceptual and organic shapes that can hardly be achieved through traditional design approach while respecting the design specification.

Further, it can bring about an intuitive workflow without expert solutions and a seamless collaboration between the designer and the simulation engineer. In addition, lattice structures can be integrated into the product design in order to generate lightweight products with sufficient strength and stiffness requirements.

A simplistic example can be seen in **Fig. 4**, and a load density distribution driven optimization of a shoe sole in **Fig. 5**.

Moreover, for the polymer AM simulation, multiscale and multiphysics thermal-mechanical models need to be considered, which involves the progressive addition of material, rapidly changing heat transfer boundary conditions, transient energy source and complex material evolution.

It is a very challenging task to take all these above-mentioned factors into consideration. However, with the 3DExperience platform, simulating the entire print process becomes much easier. One dataset and a guided assistant will take you one step at a time through the build process to produce highly accurate results. The process simulation allows engineers to predict temperature field, induced residual stresses, void generation, interlaminar failure and even warpage of a polymer part as a function of manufacturing process parameters. These prediction results can lead to minimized execution time without compromising the part quality at the same time.

Additionally, by using the 3DExperience platform, process automation and optimization can be efficiently tackled to obtain the optimal building orientation, support structures, and printing path, as shown in **Fig. 6**.

Once the AM process has been selected, the part with all its build data can be added to the virtual build plate of your chosen printer and the manufacturing process defined. Automated nesting options make sure multipart print runs are optimized and you may choose from a library of native supports and laser scan paths to best suit your part.

In addition to the above-mentioned pre-processing capability, the post-processing functionality provided on the 3DExperience platform allows users to optimize the build process even further. For example, support structures require post-print removal and some parts require additional finishing procedures, all of which can be simulated in order to choose the best process to maximize the part quality.

Further, in-service simulation of the additively manufactured part can also be carried out to evaluate its on-site performance before the real 3D printing, such as durability, impact resistance and NVH. The advantage obtained from the optimization is quite evident in an example of the pin-connection base structure in **Fig. 7**.

More importantly, it is also a business experience platform (available on premise and on the cloud) that enables a collaborative experience and effective interaction between the 3D CAD designers, simulation analysts, and production personnel. With digital technology changing the manufacturing landscape, the 3D Experience platform offers a unique advantage: maintain one single dataset, utilize different useful tools and compare various AM techniques in an effective collaboration environment.

Conclusion

Simulation techniques provided by the 3DExperience platform is the final solution to minimizing printing trial and errors prior to physical fabrication.

With its capability of enabling a variety of users to explore the process sensitivity to manufacturing parameters, the simulation insights offered by this platform allow engineers to significantly reduce physical tests, understand the key parameters driving the material's behavior, and easily create new material systems, such as lightweight lattice structures.

Fig. 3: 3DExperience AM simulation platform.

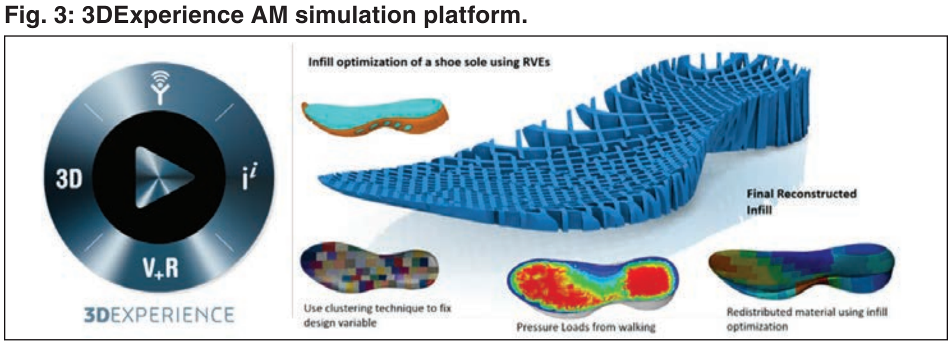

Fig. 4: An optimization resulting in a hybrid lattice structure.

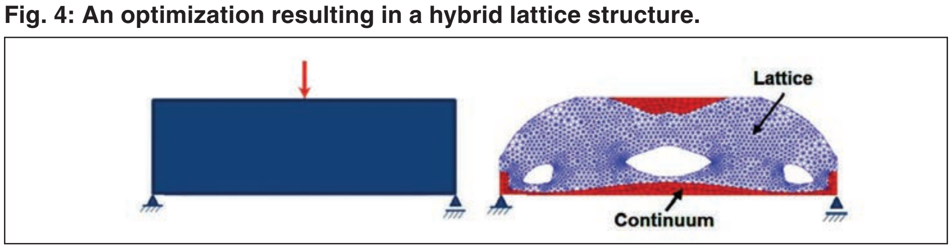

Fig. 5: Tosca topology optimization based on a pressure load.

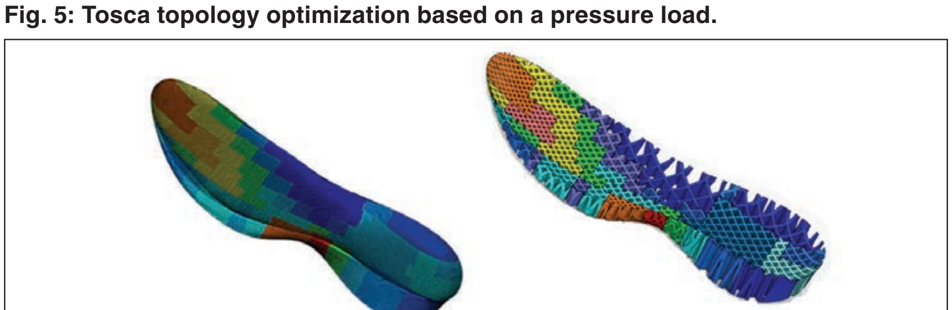

Fig. 6: Process automation and optimization on the 3DExperience platform.

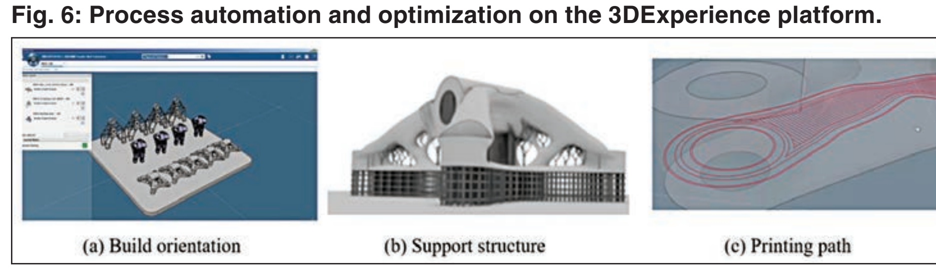

Fig. 7: Comparison of the topology optimized AM design.