

## Fused Strand Deposition Creates a Structure that Mimics Bone with Enhanced Properties

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### What is FFF/FDM?

Fused Filament Fabrication (FFF) and Fused Deposition Modeling (FDM) are essentially the same additive manufacturing printing process. FFF is the generic, open-source, term, where FDM is the trademarked term used by Stratasys. After Stratasys's patent expired in 2009, the two terms are used interchangeably.

FFF is essentially the process of layering melted thermoplastic depositing through a nozzle in subsequent layers to build 3D objects. Source 3D models are initially divided into layers, known as slicing, where the layers are analyzed as 2D planer surface areas. Perimeters are determined from each layer's 2D shape and infilled to generate each respective layer as a pseudo planar solid. The layers are stacked upon the previous layers to eventually build up the 3D object.

### What is FSD?

Fused Strand Deposition (FSD), in contrast to FFF, is a proprietary 3D printing process developed by FossiLabs in 2018, which was later acquired by Curiteva in 2020. FSD offers superior properties compared to FFF. FSD leverages the additive process to enhance material properties that are not achievable using traditional FFF methodologies. Primarily, FSD is used for the creation of fully porous, lattice-based structures that mimic natural trabecular bone. FSD is exclusive to the patented Curiteva FLMED printer hardware and software. [3,4,5,6]

FSD analyzes the 3D model in volumetric regions rather than 2-dimensional slices, enabling variable porosity (from fully dense to open pores) and non-planar strand deposition. This allows for intersecting strands that form scaffolds without strict horizontal layering. [Fig. 1]

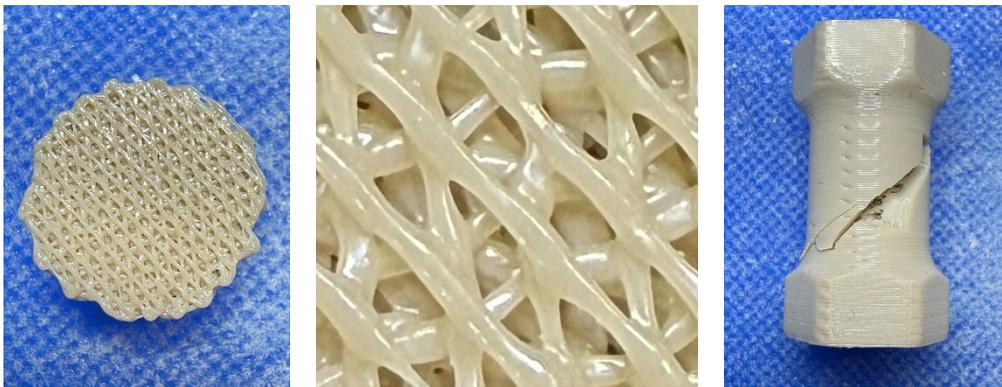
Scientifically, this approach leverages material path-dependent extrusion dynamics. During deposition, strands are stretched and attenuated under controlled tension and temperature introducing molecular alignment in the polymer chains. For PEEK, a semicrystalline thermoplastic with a glass



Figure 1, Various porous scaffolding patterns and dense infill.

transition temperature around 143°C and melting point near 343°C, this stretching promotes oriented crystallization, akin to fiber drawing in polymer processing. FSD novel methodology introduces strain-induced crystallinity by aligning the polymer chains as the PEEK transitions from an amorphous to a semicrystalline state. [2] This transition is key to improving the overall mechanical strength, toughness and dimensional stability of the 3D printed construct. The result is a lattice structure that more closely mimics the interconnected, trabecular architecture of natural bone, which provides optimal nutrient diffusion and cell infiltration. [Fig. 2]

In biomechanics, bone scaffolds must balance stiffness (to avoid stress shielding) and porosity (for tissue ingrowth). FSD enables triply periodic minimal surfaces (TPMS) like diamond lattices, which provide zero mean curvature for minimal stress concentrations and high permeability (up to 10 times that of strut-based lattices). TPMS structures in bone tissue engineering enhance fluid flow, nutrient transport, and vascularization, promoting osteoblast proliferation and differentiation.



*Figure 2, (Left) Porous scaffolding, (Middle) Close-up strand attenuation, (Right) Torsion test, multi-layer shear*

Unlike FFF/FDM stacked layers of "blob" deposition to form modeled geometric structures, which yields weak bonds, FSD's strained strands form crystalline networks with superior fatigue life. Finite element analyses confirm TPMS scaffolds reduce stress shielding by 50–70% compared to solid implants, aligning with Wolff's law for bone remodeling.

### **Surface Enhancements and Biological Advantages**

FSD additionally, creates micro/nano textures ideal for cellular attachment. Macro “pulled taffy” like textures and nano spherulites are visible under magnification. [Fig. 3] With the addition of nano chemistry (i.e., Curiteva's Inspire HA FUSE), PEEK transforms from being hydrophobic to hydrophilic. [Fig. 4]

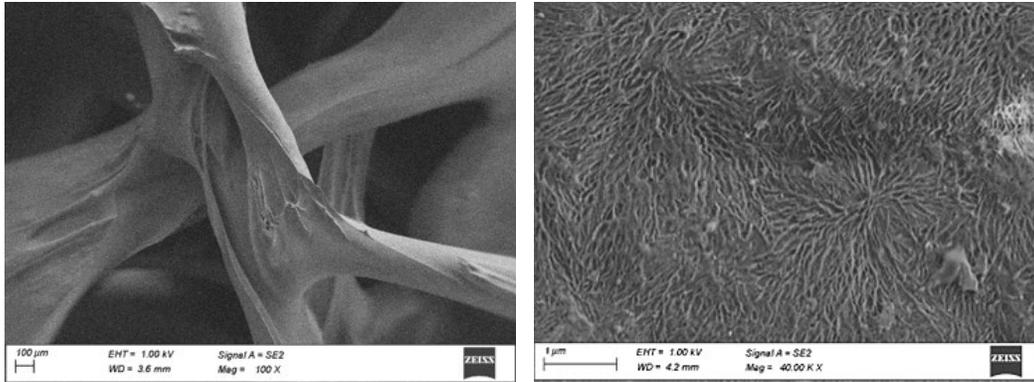


Figure 3, (Left) SEM 100X Taffy Macro Surface, (Right) SEM 40,000X PEEK Spherulites, Radial Lamellae

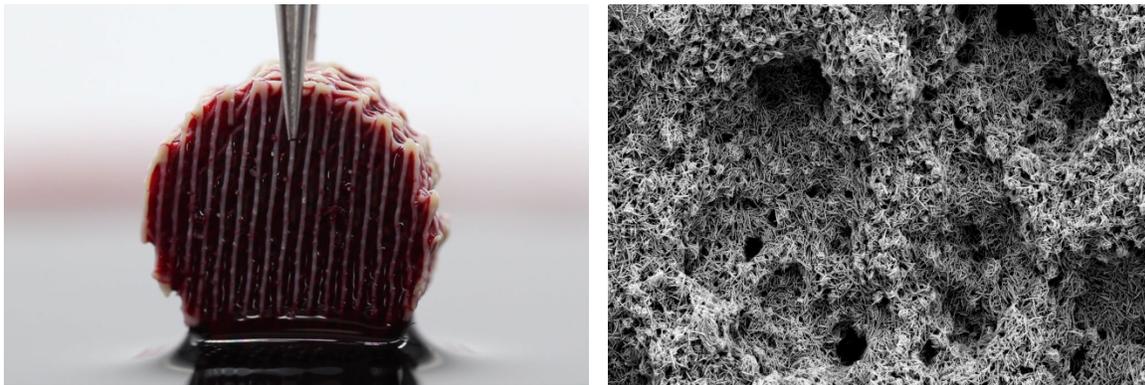


Figure 4, (Left) PEEK Hyper- Hydrophilic, (Right) PEEK Surface chemistry - HAFuse whiskers

The Inspire technology using FSD creates the ideal TPMS fully porous scaffolding with critical surface texturing. Coupled with nanometer modified surface chemistry (hydroxyapatite), an ideal environment, down regulates pro-inflammatory cytokines and up regulates pro-regenerative cellular expressions, leading to improved osseointegration. [1]

Curiteva's Inspire technology offers unmatched biological advantages over the competition. FSD PEEK becomes hydrophilic, improving protein adsorption, closer mimicking bone, and accelerating bone apposition.

In contrast, alternative available PEEK filaments with additives like biphasic calcium phosphate (BCP) or hydroxyapatite (HA) offer very minimal advantages. PEEK remains hydrophobic similar to rod-stock or injection molded devices. The natural skinning during the extrusion process encapsulates most of the blended additives and only a minimal amount is available at the surface (if any), thus reducing bioavailability and efficacy. Furthermore, it has been reported by Evonik and Invibio that addition of these fillers tends to decrease the mechanical strength while increasing the stiffness.

In summary, FSD represents a significant advancement in additive manufacturing for biomaterials, backed by polymer science and tissue engineering principles. Its ability to engineer PEEK scaffolds with bone-like properties positions it as a frontrunner for orthopedic implants. Curiteva's implementation of FSD for the Inspire product line continues to demonstrate clinical viability.

#### References:

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