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Viscous Thread Printing for Foams with Continuously Varying Stiffness

This innovation presents a method for additive manufacturing built on virtual thread instability, enabling continuously varying stiffness in fused filament fabrication (FFF) based 3D printing. This approach enables scalable, single-material production of parts with tailored mechanical properties, without the need for complex design or high-resolution printing.

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Hardware/3D Printing
Materials/Other

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What is the Problem?

In many engineering applications, there is a need for materials that exhibit varying mechanical properties such as stiffness across a single component. Traditionally, this is achieved by bonding together materials with distinct properties. However, these bonded interfaces often become points of mechanical weakness, where stress can concentrate and lead to premature failure, delamination, or cracking under load.

Additive manufacturing (AM) offers a promising alternative by enabling spatial control over material deposition. Yet, achieving continuously varying mechanical properties within a single printed part remains a challenge in materials such as foams, commonly used in cushioning, insulation, and impact or noise absorption. Two common approaches exist: one relies on explicitly designing microstructures with varying geometry, which demands extremely high print resolution and becomes impractical for large-scale parts. The other uses complex toolpath algorithms to modulate material behavior to implicitly define geometry, but these methods require extensive computational resources and are difficult to scale. Both approaches struggle to balance precision, scalability, and manufacturability.

What is the Solution?

This innovation builds on fused filament fabrication (FFF), the most widely used and accessible form of 3D printing. FFF is known for its scalability, low cost, and compatibility with a broad range of materials, making it a practical platform for manufacturing both prototypes and end-use parts. The method employs a variation of FFF called viscous thread printing (VTP), which enables the creation of foam structures with continuously graded mechanical properties. By dynamically adjusting print parameters—such as path speed and print height—during extrusion, the process leverages a natural phenomenon known as viscous thread instability. Like the patterns honey will make when poured on pancakes, this instability allows the formation of fine-scale internal structures that influence the material's stiffness and elasticity. Unlike traditional approaches that require high-resolution printers or complex design algorithms, this method achieves spatial variation implicitly through process dynamics. Demonstrated using thermoplastic polyurethane (TPU), the technique allows to produce components with tailored mechanical behavior in a single, uninterrupted print.

What Differentiates it from Solutions Available Today?

This method offers a scalable and straightforward approach to producing components with spatially varying mechanical properties. Because it builds on the widely used FFF printing platform, it requires no specialized hardware or materials and can be implemented using standard equipment with minimal modifications.

By leveraging process dynamics rather than explicit geometric design, the technique produces fine-scale internal structures that result in improved mechanical performance. Components manufactured using this method exhibit higher fracture stress, greater fracture strain, and enhanced toughness compared to those made with discrete material transitions. These improvements are especially notable even in regions with abrupt changes in stiffness, where traditional methods often introduce mechanical discontinuities.

The approach is broadly applicable across industries and use cases. In healthcare, it could enable custom orthotic devices or prosthetic sockets with localized cushioning. In consumer products, it supports the design of footwear or seating with targeted support zones. In aerospace and automotive sectors, it offers a pathway to lightweight, impact-resistant components with tailored mechanical profiles. The method is also potentially adaptable to other material classes, including metals, ceramics, and glasses, expanding its relevance to a wide range of manufacturing contexts.

References

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