Apparatus and method for dynamic characterization of materials, and a novel inspection and imaging technique for additive manufacturing

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Characterization of polymer materials: Mechanical performance of polymers tends to be highly dependent on the loading scenario and the environmental conditions and the chemical structure. For the latter, molecular rearrangements may be reversible or irreversible based on a balance between the strain energy imparted on the sample during loading and the activation energy required for irreversibility. Because of this, it can be challenging to understand/predict the behavior of polymers during deployment. Experimental mechanics setups capable of dynamically loading polymer materials while simultaneously characterizing the molecular conformational changes in the polymer structure are not currently available. The gap in the understanding of the primary impact mitigation mechanisms hinders the optimization of the effectiveness of designs for various polymer-based products.

This invention provides dynamic characterization of a test material. A terahertz (THz) time-domain spectroscopy system generates and detects terahertz waves to assess the sample. A shock wave loading system produces a shock wave in the sample concurrently with THz spectroscopy device. The ultrafast shock wave-induced changes in the index of the refraction of the sample are detected by the THz spectroscopy system. The electromagnetic THz waves after propagating through the sample are converted into a measurable electrical signal, which can be recorded and analyzed in the time and frequency domains to determine one or more mechanical properties of the sample.

Polymers, composites, and additive manufacturing: These materials are conducive to advanced manufacturing techniques such as 3D printing, and the parts and components are built layer by layer. However, the shortcomings of 3D printing include manufacturing defects, which in turn affect the mechanical performance of parts, requiring extensive post-fabrication testing and evaluation. The latter is done either destructively or nondestructively by leveraging different parts of the electromagnetic spectrum (e.g., X-ray/infrared/acoustic waves). While the existing nondestructive evaluation techniques can shorten the inspection and testing times before deployment, they are not suitable for concurrent inspection during 3D printing; require physical contact with the part using viscous coupling media (ultrasound) or pose safety concerns (X-ray computed tomography).

This invention offers to be the first in-situ nondestructive inspection and imaging technique suitable for seamless integration within any 3D printer enclosure (heated or otherwise) by utilizing the under-investigated terahertz regime of the electromagnetic spectrum. Its evaluation subsystem is not printer-specific and provides real-time reconstruction of the collected terahertz images to create tomograms for inspection and evaluation.

ADVANTAGES

- Dynamic loading of polymer materials while simultaneously characterizing the molecular conformational changes in their structure
- Standalone, in-situ nondestructive inspection and imaging
- Independent of the printer design
- Real-time creation and evaluation of tomograms
- Greater manufacturing yield, reduction of waste

APPLICATIONS

- Integration into standard printer or advanced robotic printing systems for the 3D printing of polymers and composites, and assessment of the structural integrity of 3D printed parts during printing.
- 3D printing in other industrial domains
- Wide range of polymer-based products (cellular phones, automobiles, household goods, walking shoes, protective gears, bulletproof structures, *etc.*)

PUBLICATIONS

- U.S. Patent Application No. 17/770,277 – “Apparatus and method for dynamic characterization of materials”
- Pending U.S. Provisional Patent Application
- Research Publications List

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