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4D printing of photoreactive shape memory polymer for smart building applications

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Abstract

The integration of three-dimensional printing and smart materials in the construction industry enables the development of adaptive and energy-efficient buildings. This work aims to fabricate and characterize a bistable photoreactive material for integration into the windows of a building façade. The smart material proposed in this work will be used to design structures that will directly react to solar intensity and autonomously regulate shading without the need for external actuation or sensing, providing a self-regulating solution inspired by dynamic façades such as the Moucharabiehs of the Arab World Institute in Paris and the Al Bahar Towers in Abu Dhabi. The proposed material is based on thermoplastic polyurethane (TPU)-based shape memory polymer (SMP), which can deform from its original shape upon heat activation. To enable shape memory activation in response to sunlight, carbon black (CB) and PDPP3T are incorporated into the TPU matrix, enhancing light absorption and photothermal conversion properties and allowing the material to be activated directly by solar irradiation. The CB is processed through extrusion to ensure homogeneous dispersion within the TPU matrix, while PDPP3T is introduced via immersion to enable controlled surface functionalization. A comparative analysis is performed to evaluate the effects of these additives independently and in combination to identify the optimal formulation for achieving sufficient heat generation to reach the shape memory activation temperature under solar irradiation. To introduce bistability and enable a reversible shape memory effect, a carbon fiber-reinforced PLA film is integrated into the structure. The mechanism operates as follows: under sunlight exposure, the TPU absorbs light energy, generating heat through photothermal conversion, which activates its shape memory effect, causing the structure to expand and block sunlight. Conversely, in the absence of sunlight, the PLA film's elasticity restores the structure to its original, more contracted state, enabling light transmission and establishing a self-regulating shading system. This material is used to manufacture lattice structures via 3D printing using fused deposition modeling (FDM). These lattices will serve as the basis for adaptive architectural elements, offering a sustainable, energy-efficient shading solution that contributes to the development of Net Zero Energy Buildings (NZEB) by reducing dependence on active climate control systems.