Low-Cost Nanocrystalline Nickel Reinforcement of Additively Manufactured Polymers for Extreme Industrial Environments

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Despite its accessibility and geometric versatility, polymer additive manufacturing remains limited in industrial use due to the inherent structural and chemical vulnerabilities of polymers. While nanocrystalline nickel reinforcement offers a path forward — achieving superalloy-class performance on metals — its application to polymers has been prevented by high interfacial stresses and proprietary manufacturing barriers. This research addresses these challenges by developing a low-cost, dual-layer methodology for nanocrystalline nickel reinforcement of 3D-printed polymers. An autocatalytic electroless nickel-phosphorus (ENiP) mid-layer is deposited onto sensitized and palladium-activated polycarbonate, establishing a molecularly anchored, conductive foundation. This foundation enables nanocrystalline nickel synthesis via pulsed-current electrodeposition in a nickel sulfamate bath with saccharin and L-cysteine as grain refiners. Nanoscale grain refinement was achieved through an optimized 1:10 duty cycle (3 ms ON / 30 ms OFF). The resulting composite shell measures ~100 μm. Coated polycarbonate achieved a surface hardness of 800 HV (a 40-fold increase over the base substrate), with the coating exhibiting an intrinsic strength of 1,580MPa while occupying only 2% of the cross-sectional area. Environmental testing confirmed the shell effectively resists 1300°C thermal loads and aggressive chemical solvents. Applicability to complex industrial geometries was demonstrated through the design and fabrication of a centrifugal turbopump. This approach provides a pathway to superalloy-class surface properties on polymer substrates using commercially available reagents and benchtop equipment, reducing production costs by over 99% compared to metal additive manufacturing.

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