Abstract

An ever-growing demand for small-scale functional components and the increasing trend of miniaturization in functional systems have led to the rise of microsystems technologies in recent years. Traditional manufacturing processes face limitations in producing precise small-scale tubular and complex structural profiles while maintaining required functional capabilities. Many unconventional manufacturing processes, including electrochemical-assisted techniques, have been revitalized to meet the need for miniaturization. Electroforming, as one of these unconventional processes, enables the low-cost fabrication of high-precision components in cutting-edge micro and nanotechnology domains at room temperature. This work proposes a cost-effective approach for manufacturing metallic and composite tubular structures as well as for metallic deposition on flat and complex surface profiles using an "in-house pulse electroforming" setup.

In the upcoming chapter of this thesis, we present the amenable fabrication methodology for small-scale tubular structures, addressing the challenge of fluidic transportation without outflow, applicable in microfluidics, micro heat exchangers, and various biomedical microdevices. We also developed super hydrophobic surfaces over the electroformed structure, achieving a water contact angle of more than 150 degrees on both the interior and exterior surfaces. Additionally, with the widespread use of millions of dyes in the textile industry, there is an engineering challenge to remediate the wastewater generated and protect natural water sources. In this context, we developed nanofunctionalized electroformed tubes for the degradation of Azo dyes, which are considered poorly biodegradable industrial pollutants. Copper/graphene oxide electroform tubes are also developed using an in-built setup and these substrates are utilized for photocatalytic degradation of organic dyes (methyl orange and methylene blue) under sunlight irradiation. Additionally, we developed nano-sized SiC embedded Cu tubular structure, thereby enhancing its mechanical strength and corrosion resistance. We investigated the impact of pulse frequency, duty cycle, bath agitation, and salt concentration with the help of statistical tool (ANN, ANFIS) revealing nuanced effects on surface properties, microhardness, compression, corrosion, and hydrophobicity. Furthermore, the surface micromanufacturing technique is explored to develop porous copper electrode with unique structural and functional properties, holding potential for a wide range of applications in catalysis, sensing, energy storage, and filtration.

In addition to it, another work was performed on 3D-printed complex structures to enhance their mechanical strength and functional properties, through a combination of pyrolysis and electrodeposition techniques. Digital light processing (DLP) based additively manufactured structures underwent pyrolysis, transforming into carbon with a 90% of volumetric shrinkage, followed by Ni-Cu bimetallic electrodeposition for hydrogen evolution reaction (HER) and microelectromechanical (MEMS) applications.

In another study, we explored electrochemical energy to propose an effective solution for the treatment of textile wastewater before discharging it into natural waterbodies, which includes the real-time photocatalytic degradation using novel ZnO caterpillars along with the electrochemical processing. Additionally, to reduce the processing time, we also performed the analysis by exploring the ultrasonic-assisted technique along with the statistical optimization of parameters.

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