Carbon and Carbide Origami

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Biography

I passed my Bachelor of Engineering with distinction from Indian Institute of Science Engineering and Technology, Shibpur (Formerly Bengal Engineering and Science University) in 2013. I had acquired research experiences in the field of microfabrication, microfluidics and nanotechnology in several research labs in India and USA. I worked as undergrad summer scholar in Indian Institute of Technology Kharagpur in 2011. Two research projects I completed in the BioMEMS laboratory of University of California, Irvine in 2012 as an exchange scholar. I worked as research associate for 6 months in Nanotechnology laboratory of Indian Institute of Technology Kanpur in 2013. Currently I am a student member of American Electrophoresis Society. My research interest includes microfabrication, carbon electrode dielectrophoresis, separation and manipulation of pathogenic cells for easy detection, nanomaterial synthesis, and carbon material synthesis from bio-precursors.

Overview:

Here we present an innovative methodology for the rapid manufacturing of reproducible carbon and carbide origami structures. This method utilizes a Cutting Plotter coupled with a ballpoint pen to pre-crease paper which can then be easily folded by the user. Carbonization of such paper origami shapes results in carbon origami structures. Further heat treatment of a metal precursor infiltrated paper origami results in carbide origami structures. This procedure makes it possible to produce high quality origami structures made of carbon and carbide structures in geometries challenging to obtain through other manufacturing methods.

Motivation

Origami is an ancient Japanese method of paper folding. Any complex 3D shape can be fabricated easily just by folding a planar paper along creases. The paper is composed of cellular network of cellulose fibers, which is an inexpensive and renewable precursor to carbon [REF]. Hence carbon origami could make it possible to fabricate 3D complex carbon shapes which are difficult and expensive to fabricate in conventional manufacturing process. Paper derived carbon has unique properties such as high electrochemical response and reasonable electrical conductivity, which are preferable for sensor applications. Hence carbon origami could be useful as a multifunctional material, such as light weight structural material which can be used as sensor as well. The paper can be also potentially used as a carbon source for carbide synthesis. Hence it can be also possible to make 3D complex carbide origami structures.

State of the Art

Traditionally, paper origami has been used for decoration and art. But the origami structures feature some unique features such as low density and high resilience to compressive stress. Applications of origami range from deployable structures such as emergency shelters and solar sails to shock absorbers in sports equipment [1] and packaging materials [2]. Although paper origami is mostly used to complement theoretical developments and new folds, most of the demonstrated applications make use of synthetic resins [1], acrylic [3], and aluminum foil [4].

Intellectual Merit

The intellectual merit of this work lies in the fact that any 3D complex structure made of carbon or carbide can be manufactured just by folding papers followed by heat treatment. No complicated or expensive equipment or process is needed for this. This process also allows for easy fabrication of multifunctional structures.

Broader Impact

3D complex carbon and carbide shapes can be fabricated using an inexpensive and easy paper folding method. Furthermore, paper serves here as a renewable carbon precursor, which makes our process environment-friendly and sustainable.

Research Approach

Carbon origami fabrication process starts with pre-creasing of a paper in order to establish a replicable, reliable and easy way of paper folding. Fisher-brand chromatography paper was chosen for origami because of its cellulosic nature and minimal impurity. For the pre-creasing method, CAD designs for the creases were made in solidworks. The paper was then creased following the CAD designs with a ball-point pen mounted on a cutting-plotter. Once the paper was creased properly, the paper was folded manually along the creases to obtain the 3D shape of paper origami. The paper origami shape was carbonized in a tube furnace at 900 °C in nitrogen to obtain the carbon origami shapes. For tungsten carbide origami, the paper origami shape was immersed in an aqueous solution of 20% ammonium meta-tungstate (AMT). The AMT infiltrated origami shape was heat treated at 1300 °C in vacuum to obtain an origami shape made of tungsten carbide. Three origami tessellations, Miura-ori, Yoshimura and water-bomb base were fabricated for both carbon and tungsten carbide using this process. Different sizes of these origami tessellations were fabricated to test the scalability of this process.

X-ray diffraction (XRD) spectroscopy was performed to investigate the material composition of the origami shapes. The microstructure of the origami shapes was characterized by scanning electron microscopy (SEM, S4800, Hitachi, Japan). To investigate the mechanical strength, compressive test was performed for the miura-ori structures. Till now the mechanical testing has been performed only for the carbon origami structures.

Findings to Date

The carbon and tungsten carbide preserved the original shape of the paper origami, although a significant amount of weight loss and shrinkage occurred during the heat treatment. The scalability of this process appears to be dependent on the complexity of the origami structures. The compressive strength test showed that the specific strength of the carbon origami is 2.2 times higher than the paper origami structures. Also small error limit observed in the compressive test results reflects the replicability of this process.

Conclusions

With our origami technique, it can be possible to fabricate 3D complex shapes of carbon and carbide which are difficult to manufacture in conventional manufacturing techniques. This technique also allows for single step fabrication of multi-material complex 3D shapes. Different portions of a paper origami shape can be selectively infiltrated with different metal precursor. Heat treatment of such origami shape should result in a multi-material origami shape, which might be used for different applications such as battery, structural material and sensor material at the same time.

References

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