TAKING 4D BIO/PRINTING TO CLASSROOM

Ali Zolfagharian[1], Mahdi Bodaghi[2], Hamid Reza Jarrah[2]

1 : School of Engineering, Deakin University, 3216, Geelong, Australia
a.zolfagharian@deakin.edu.au

2 : Department of Engineering, School of Science and Technology, Nottingham Trent University, Nottingham NG11 8NS, United Kingdom
Mahdi.bodaghi@ntu.ac.uk

Abstract

The emergence of four-dimensional (4D) printing in additive manufacturing (AM), which requires knowledge in multi-physics, chemistry, and engineering skills, is bringing many applications in biomedical, robotics, aerospace, and food industries. The increased usage of AM technology and smart materials in industry means that companies are seeking to develop and manage production system for academics with the multidisciplinary abilities and knowledge. This enables a high interdisciplinary platform for research and project modules suitable to be used in the academic environment for hands-on students training. This paper proposed an easy to implement and follow 4D bio/printing module well designed for students and early career researchers to the filed to learn different aspects of skills and knowledge as part of their engineering course giving them a valuable advantage in an increasingly competitive job market and higher degree research.

Introduction

Four-dimensional (4D) [1] printing is a promising manufacturing method for controlling self-morphing in custom-design structures. This study strives to demonstrate a readily implemented practical demonstration of 4D printing control parameters such as different geometrical design and stimulus effects on the bending angle of the 4D-pritned structures [2]. The self-morphing 4D printing refers to transformation of printed items from flat structures into three-dimensional (3D) assemblies when an external stimulus is applied [3].
Light stimulus is a practical means to produce heat using a photo-thermal conversion, since it has the capacity to be remotely controlled, rapidly switches on and off, and uses clean and sustainable energy. In this case study, a simple 4D printing approach is introduced in transforming a flat sheet into spatial structure using near infrared (NIR) light. An FEM modeling of SMP substrate and 4D-printed patterns is developed. Experimental tests are carried out to validate the model. The proposed model predicts the final shape of the 4D-printed structure with excellent qualitative agreement with experimental studies. The study provides guidelines for the learning principles of 4D printing, design, modeling, FEM simulation, and practical experiment of 4D printing with the least equipment. This study requires the following materials: 1) An inexpensive commercial pre-strained polystyrene (PS), called Shrink Film. 2) An infrared lamp. 3) Extrudable paste, e.g., chitosan hydrogel used here. 4) Black dye, e.g., carbon black. 5) A syringe to replicate printing, e.g., Bioplotter 3D printer used here for fast and accurate manufacturing.

4D Printing Design and Fabrication

In this work, we've chosen to print using pre-strained, or Shrink Film, since it is readily available, affordable, transparent, and has appropriate rigidity. Pre-strained Shrink Film is a PS sheet that was cooled below its glass transition temperature (T_g) while being stretched above the T_g, and then was annealed. When they are heated above T_g, these materials release their inherent tension. For this investigation, the shrinkage has been found to be up to 60% when the T_g is around 102 °C.
First the PS films are cut into the same dimensions of 50mm×10mm. Then the center of the film is marked. In general, for this experiment, any available paste that could be extruded using a syringe can

be used to conduct the experiment part replicating the 4D printing. Then, the black colour paste should be prepared and loaded in a syringe and the earlier designed patterns shown in Figure 1 are printed from the centre of the PS film. In this work, medium molecular weight chitosan (with a deacetylation degree of 75–85%) and acetic acid were utilised (Sigma Aldrich, Australia). At 40 °C for 3 hours, a combination of 5 g chitosan in 100 ml acetic (1 v/v %) was formed. Following 1 hour of mixing, 250 mg carbon black particles were added to create the final polymer black. The created ink was sonicated to eliminate bubbles, since their presence degrades printing quality. Then, as shown in Figure 1, several hinge designs with the same quantity of ink and strand thicknesses were printed in a 10mm×10mm square on the PS film. Then, the printed patterns are dried in an oven at 50℃ for 5 hours.

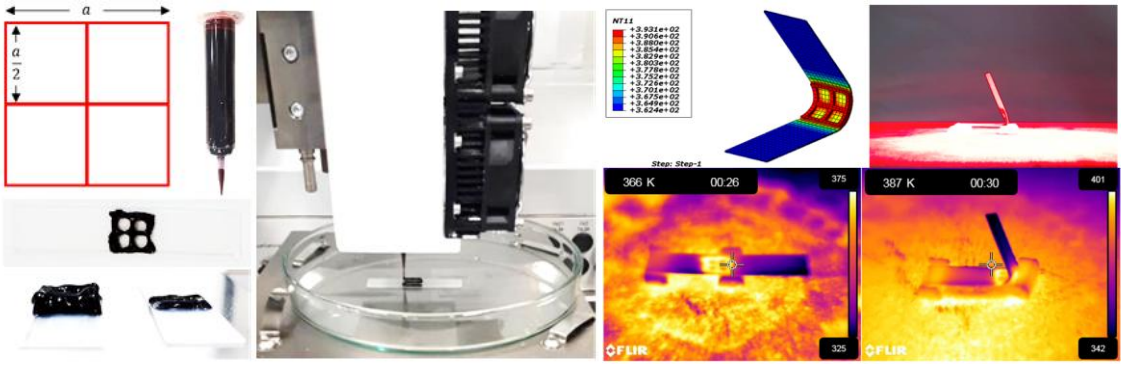

Fig. 1 – Active hinge square pattern with different print height, ink syringe, and 3D-Bioplotter (left), simulation and experimental results (right).

FEM thermal-mechanical coupling in ABAQUS and Experimental Results

In ABAQUS, the FEM models are generated. PS film and 4D-printed design geometry are designed in CAD, then exported to ABAQUS. The default physical heat transfer model in solids is used and boundary conditions and sources are set. Based on the mechanical and thermal properties parameters of the PS and hydrogel ink the material library is utilised and updated in ABAQUS. Initial temperature is set at 313.15 K, as the ambient temperature of the PS film is on the hotplate, at the time of beginning of irradiation of NIR source. A NIR lamp is placed at a suitable distance (250 mm) to irradiate the IR light evenly on the actuator with maximum irradiation intensity of 3.5 mW/mm^2. The thermographic camera shows the temperature distribution of each PS film, and a digital camera is used to capture the sample bending angles in a side view. The maximum deformation has been recorded and compared with the simulation results demonstrated in Figure 1.

Conclusions

A controlled bending of structures using 4D printing was presented in this study. To fulfil the main aim of the work to be reproducible for engineering students and lecturers to practice 4D printing in class, the minimum requirements of facilities and materials to replicate the 4D printing were opted. To estimate the bending behavior of the 4D-printed structure, a thermal-structural FEM model was developed in ABAQUS. The testing results confirmed the validity of the model and demonstrated that the model used in controlling the 4D printing bending angles was successful.

References

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