THE ROLE OF DEFECTS IN 3D PRINTING OF BIO-INSPIRED CELLULAR COMPOSITES

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1 Introduction

Cellular composite materials are widespread in nature (e.g. wood, bamboo, bone) and in advanced engineered structures such as aircraft, ship hulls, and wind turbines blades. The prevalence of cellular materials and structures in our everyday life easily goes unnoticed. However, in many instances where strength, stiffness, energy-efficiency and lightweight are required (often concurrently), cellular materials are often considered as the preferable design by experienced design engineers. Additive manufacturing (AM) technologies, also known as 3D printing, opens up new opportunities to fabricate such materials with different microstructures. Combined with computational tools, it profoundly extends engineers' ability to selectively place materials where they are needed in their designs.

From the performance aspect, AM fabricated parts are subjected to defects unique to these processes, which can be originated from the printing process, material characteristics or a combination of both. To make high quality structural and functional components, these defects need to be eliminated through careful process parameter control to achieve desirable engineering and structural properties [1]. The mechanical properties of bio-inspired 3D printed cellular structures can be severely limited by the presence of such defects and printing time. It is imperative that the process may be optimized to minimize these defects as underpinning for any subsequent research. To date, quantifying the effect of defects on the quality of printed structures has been neglected in the literature; understanding the origin of these defects and controlling them while printing durable and cost-efficient structures are the main objectives of this research. To achieve these objectives, we address the fabrication, testing and modelling of the mechanical properties of 3D printed cellular materials with various cell geometries resembling those commonly found in wood and bamboo.

2 Methodology

The mechanical properties of a structured cellular material rely equally on its cell geometry and the materials from which it is made. Following this rationale, by only changing the cell architecture/morphology, a new set of properties can be achieved from structures made from the same material. To demonstrate the potentials of 3D printed cellular structures, hexagonal and square cells are adopted, similar to those reported in the litreature [2, 3]. Additionally, we study the performance of specimens with mixed cells constituting of both square and hexagonal geometries inspired by hardwoods such as balsa [4].

Fused deposition modelling (FDM) and powder-based printing processes are employed for fabricating complex geometrical parts with a variety of feed materials. Current commercial printing technologies result in a unique set of internal and surface defects. If not eliminated, these defects can have detrimental effect on the structural properties of the fabricated parts. Process defects inherent to specific print geometries may also be present. In preparation for specimen fabrication, we therefore aim to first identify the origins and degree of these defects and devise a printing strategy to either minimise or completely eliminate these defects. Three state-of-the-art printers which are available in UTS ProtoSpace are chosen for assessment. The quality and performance of printed structures are then inspected visually and examined mechanically under axial and bending loads, respectively.

3 Results

Qualitative and quantitative data on the material properties, visible defects, dimensional accuracy, printing cost and lead time are collected and compared. Preliminary results suggest that the print

direction and choice of material could significantly affect the quality of parts (see Figure.1 and 2) as well as the printing time (Table 1).

Fig. 1. Print iteration 1: honeycomb structures with thick cell walls made of Onyx (left) and ASA (right). The ASA honeycombs exhibit small defects on the surface.

Fig. 2. Cross section profiles of beams with REG and Mix cells using ASA. Note that the cell walls are thinner than those in Figure 1.

Material limitations unique to fabricating honeycombs with small dimensions (Fig. 2) are reported. Furthermore, the differential shrinkage rate of thin cell walls during printing causes warping in some samples which could lead to part rejection.

Although defects may not be noticeable in small parts (prototypes), their effects on the mechanical performance of large parts (e.g. beams and columns) are shown to be significant. Furthermore, results suggest that cost, and printing time are among the other challenges that prevent us from fabricating very large structural elements in practice.

Table 1. Comparisons of printing cost and time

Set	Cell Type	Cost	Time
1	REC	Onyx (AU$ 31.20)	Onyx (10 hours 17 minutes)
		ASA (AU$30.76)	ASA (2 hours 17 minutes)
2	REC	similar to set 1	N/A
3	REC	ASA MIX cells (AU$ 107.96)	ASA (13 hours 25 minutes)
		ASA REG cells (AU$96.04)	
	MIX	Onyx MIX cells (AU$130.79)	Onyx (25 hours)
		Onyx REG cells (AU@129.28)	

4 Conclusion

Cellular structures coupled with additive manufacturing offer a novel possibility for mechanically-efficient, bio-inspired complex architectures to be integrated into our designs and applications. Primarily, we examine the scalability of Fused Deposition Modelling (FDM) technology by fabricating geometrically-intricate honeycomb beams with cell wall thickness of 1 mm and smaller (~ 0.4-0.1 mm). The feasibility of such technique as mainstream manufacturing process is assessed through the collection of data on cost, build time, presence of defects and their effects on the mechanical properties of finished cellular beams and columns. Results demonstrated that constraints in dimensional accuracy, economy and the presence of small defects should be overcome to realize the full potentials of 3D printed cellular structures. The long-term and fatigue behaviour of such elements also need more in-depth research.

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