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Experimental and numerical modelling of mechanical properties of 3D printed honeycomb structures

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ABSTRACT

In recent years, 3-D printing experts have laid emphasis on designing and printing the cellular structures, since the key advantages (high strength to weight ratio, thermal and acoustical insulation properties) offered by these structures makes them highly versatile to be used in aerospace and automotive industries. In the present work, an experimental study is firstly conducted to study the effects of the design parameters (wall thickness and cell size) on the mechanical properties i.e *yield strength* and *modulus of elasticity* (stiffness) of honeycomb cellular structures printed by fused deposition modelling (FDM) process. Further, three promising numerical modelling methods based on computational intelligence (CI) such as genetic programming (GP), automated neural network search (ANS) and response surface regression (RSR) were applied and their performances were compared while formulating models for the two mechanical properties. Statistical analysis concluded that the ANS model performed the best followed by GP and RSR models. The experimental findings were validated by performing the 2-D, 3-D surface analysis on formulated models based on ANS.

1. Introduction

With the increasing demand for sustainable product development, scientists have shifted their focus on producing cellular structures having minimum weight with high mechanical strength. In this context, conventional manufacturing operations such as casting, machining, forming may not be suitable because it takes longer time and need specific tooling for fabrication of these complex structures [1–3]. Over the years, these manufacturing operations have evolved into additive manufacturing (AM) process, which has been proven to be a suitable fabrication technology for designing the complex shaped parts in short span of time [4,5]. Among AM processes, fused deposition modeling (FDM) is a popular extrusion based process which fabricates functional prototypes by depositing layer by layer of polymer materials inside a temperature controlled environment [6]. It is important to realize the relations between the process parameters and characteristics of the FDM printed prototypes, which could be useful in improving the functional quality of the prototypes. One way to achieve this is to develop new materials having superior characteristics than conventional materials, for which complete understanding of material science is necessary and another convenient approach is by suitably adjusting the process parameters during the fabrication stage so that the properties of the fabricated prototype can improve [7–10].

Literature reveals that the proper adjustment of input parameters (related to both machine and geometry) can improve the properties of the FDM functional prototypes [11–14]. Many researchers have deployed physics-based models to improve the properties cellular prototype [15–19], but their formulation needs in-depth knowledge of the process, which may be a cumbersome task. One promising alternative to this could be to drive the formulation of models from only the given data and perhaps this could be an interesting means of understanding the complex and dynamic nature of the process. In this context, several well-known computational intelligence (CI) methods such as genetic programming (GP), automated neural networks search (ANS), fuzzy logic and support vector regression can be applied for formulating models of the properties of the 3-D printed parts [20–24]. Other class of methods include the statistical methods such as response surface regression (RSR) can also be applied in circumstance of smaller set of data samples. Due to complex mechanism of the FDM process, the pre-assumption of the model structure is always a difficult task. To the best of author's knowledge there is hardly any research that focuses on the combined experimental and numerical investigation in developing functional expressions/models for studying the mechanical of the FDM printed honeycomb cellular structures.

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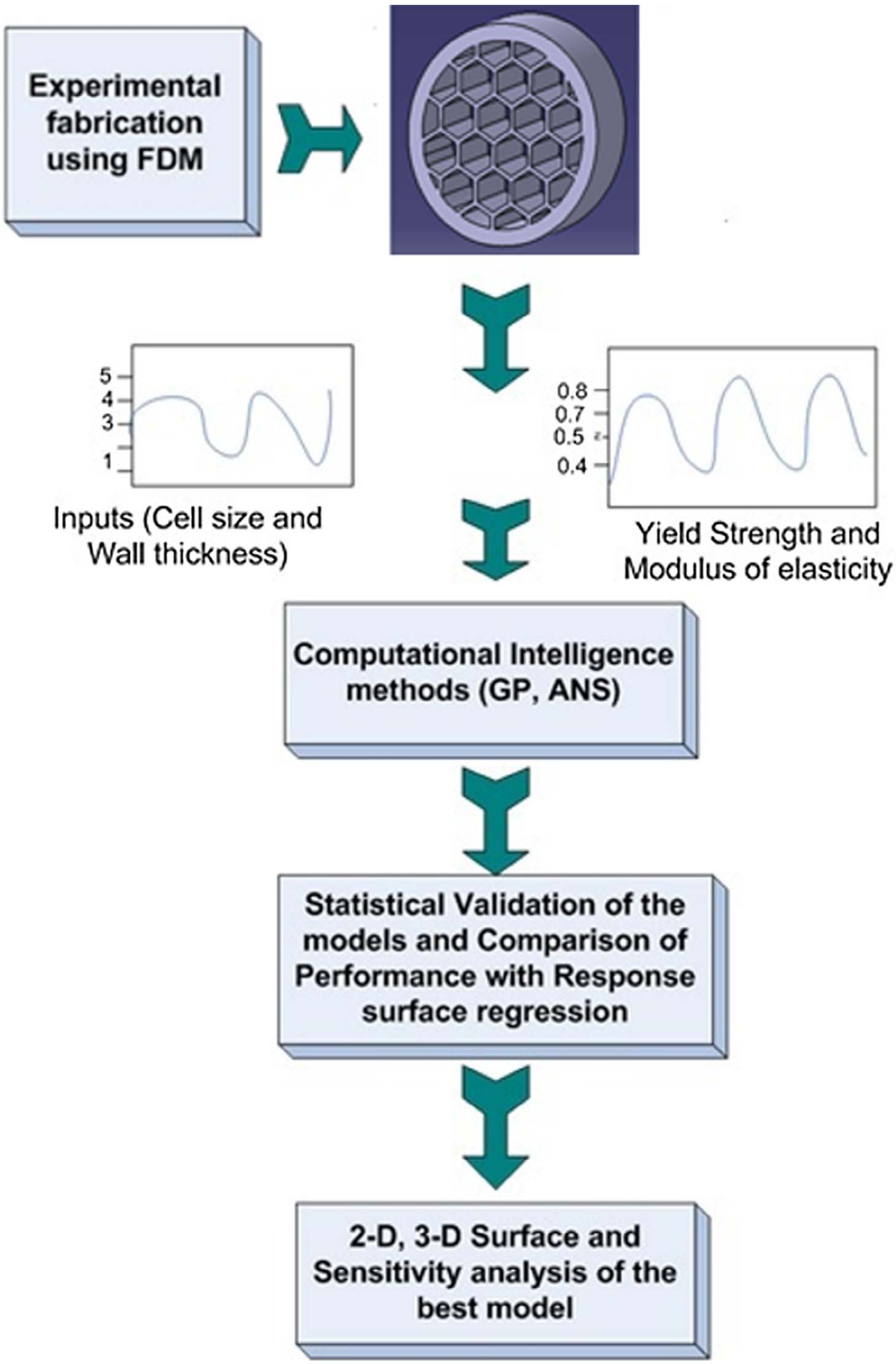

Fig. 1. Process flow for modelling mechanical properties of honeycomb cellular structure.

Therefore, in this work, the experimental study was firstly conducted by deploying the Stratasys FDM technology to fabricate hexagonal honeycomb structures with different cell sizes and wall thickness (input parameters). Based on the different values of these two input parameters, the two mechanical properties such as the yield strength and stiffness (modulus of elasticity) of FDM printed structures was measured. Further, three CI methods such as GP, ANS and RSR were applied for modeling the two mechanical properties (output) of FDM fabricated cellular structures. 2-D. 3-D surface and sensitivity analysis were performed on the best method to study the main effects of each input parameters on the two mechanical properties of FDM printed structures. The experimental finding of the present study was then validated by the obtained best models.

2. FDM experimental details

2.1. The experimental details of the FDM process

An essential procedure of FDM is the nozzle depositing heated thermoplastic sequentially on the base plate or previously re-melted