Measurement 75 (2015) 210–217

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Measurement of environmental aspect of 3-D printing process using soft computing methods

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ARTICLE INFO

Article history:
Received 21 February 2015
Received in revised form 7 April 2015
Accepted 20 April 2015
Available online 27 April 2015

Keywords:
Selective laser sintering
Soft computing methods
Open porosity prediction
3-D printing
Environmental aspect

ABSTRACT

For improving the environmental performance of the manufacturing industry across the globe, 3-D printing technology should be increasingly adopted as a manufacturing procedure. It is because this technology uses the polymer PLA (Polyactic acid) as a material, which is biodegradable, and saves fuel and reduces waste when fabricating prototypes. In addition, the technology can be located near to industries and fabricates raw material itself, resulting in reduction of transport costs and carbon emission. However, due to its high production cost, 3-D printing technology is not yet being adopted globally. One way of reducing the production cost and improving environmental performance is to formulate models that can be used to operate 3-D printing technology in an efficient way. Therefore, this paper aims to deploy the soft computing methods such as genetic programming (GP), support vector regression and artificial neural network in formulating the laser power-based-open porosity models. These methods are applied on the selective laser sintering (a 3-D printing process) process data. It is found that GP evolves the best model that is able to predict open porosity satisfactorily based on given values of laser power. The laser power-based-open porosity model formulated can assist decision makers in operating the SLS process in an effective and efficient way, thus increasing its viability for being adopted as a manufacturing procedure and paving the way for a sustainable environment across the globe.

1. Introduction

Mass and customized production of complex shaped products contributes to higher economic growth. During production, the need for energy and materials grows exponentially, which is not considered as environmentally sustainable. As a fairly new concept and advanced technology for the mass customization of products, 3-D printing could be quite beneficial to environmental sustainability. It is because the technology uses the polymer PLA (Polyactic acid) as a material, which is biodegradable, and saves fuel and reduces waste when fabricating prototypes. In addition, the technology can be located near to industries and fabricate raw material itself, resulting in reduction of transport costs and carbon emission.

Among the 3-D Printing processes (Fused deposition modeling (FDM), selective laser sintering (SLS), selective laser melting and stereolithography), SLS deploys a laser beam to selectively fuse powder into a designed solid object layer by layer [1]. Prior studies found that the features of SLS fabricated components including porosity strength, density, shrinkage ratio, etc., have high dependence on parameters such as the material and powder properties and other machine specifications such as laser power, scan speed and scan spacing. For attaining higher environmental sustainability across the globe, this process should be increasingly adopted as a manufacturing

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http://dx.doi.org/10.1016/j.measurement.2015.04.016
0263-2241/

procedure. However, due to its high production cost and increased power consumption, the technology is not yet being widely adopted.

It is important to choose the optimum input parameter values (including laser power) since the quality of the components fabricated from the SLS process can be improved resulting in higher productivity and improved environmental performance [2,3]. In this context, it is important to understand the process behavior. Due to complexity of the process, it is difficult to understand the nature of the effect of these parameters on the component characteristics. To the best of authors' knowledge, this problem is not just associated with SLS process but also with other major 3-D printing processes such as FDM and stereolithography. This problem of understanding the effect of process parameters has indeed shifted the focus and motivated researchers towards pursuing the investigations on the modeling of additive manufacturing processes [4–7].

In the perspective of modeling additive manufacturing processes, Garg et al. [2], recently conducted a survey on applications of empirical modeling methods in various processes such as FDM and SLS. It is worth noting that extensive studies were focused on formulating the models for the characteristics of density and shrinkage ratio of the SLS fabricated parts [8–14]. Only a few studies related to the porosity characteristics were conducted. The models, based on the physics behind the process, can be formulated. However, it may be a difficult task because the SLS process is dynamic and complex in nature due to the occurrence of multiple phenomena, such as transmission and absorption of energy, heating of the powder bed, sintering and cooling of the components [3].

It would be useful to develop a scientific approach for formulating models based on available data since the hidden principles behind the process on using these models could be understood [15–22]. From the literature, it was found that the novel advanced optimization methods are proposed by hybridizing differential evolution algorithm with receptor editing property of immune system [23–25], artificial bee colony algorithm with Taguchi's method [26,27], differential algorithm with Taguchi's method [28], cuckoo search algorithm (CS) [29] and immune algorithm with hill climbing local search algorithm [30,31] for optimization of properties of materials. To meet this objective, several well-known soft computing methods, such as genetic programming (GP), artificial neural networks (ANN), and support vector regression (SVR), can be applied to formulate the relationship between the output and input process parameters of the RP processes. One objective of the present work (Fig. 1) is to explore the ability of these soft computing methods in the prediction of the open porosity of an SLS fabricated prototype. Experiments on SLS are conducted with the measurement of open porosity of the fabricated prototype based on the three input variables (the layer thickness, the laser power and the laser scan speed). The methods are applied on the data obtained from the experiments and its performance is compared using the statistical metrics.

2. SLS experimental set-up

2.1. Experimental set-up

The experimental materials being tested is a mixture of ASTM F1185-88 standard hydroxyapatite powder (P218R, Plasma Biotal Ltd, UK) and a standard SLS polymer powder, Polyamide-12 (PA-12) (Duraformw, 3D Systems, Herts, UK). Details of operating conditions of SLS process are given in Savalani et al. [32]. Within the same ratio which was mentioned in Bonfield et al. [33] on HAPEX®, given material was compounded in a Betol BTS40L twin screw extruder (Betol, Luton, UK) to manufacture the HA–PA composites with 78 wt%f HA content. The ratio was formulated such that 73 wt% could be incorporated to achieve even distribution of the HA particles. The milling was conducted by the centrifugal mill rotating at 14,000 rpm. A tumbler was used and rotated at 40 rpm up to 3 h to prepare the mixture with uniformly distributed particles.

The SLS experimental system includes the Synrad 48-1-28 CO_2 continuous laser with a purpose built powder bed chamber and control system. Specifications of the laser include the maximum average laser power of 10 W and laser scan speed of 10,000 mm/s. The powder bed chamber is a 103 mm diameter cylinder. With the help of an infrared sensor, the powder bed temperature was always maintained at around 166 °C (6 °C below the onset melt temperature (172 °C) of HA polyamides). Nitrogen gas has been introduced as inert gas for the environment as well since the oxygen level must be kept below 5% in the apparatus. HA–PA experiment specimens were in size of 1 × 3 × 21 mm (height × breadth × length) [34].

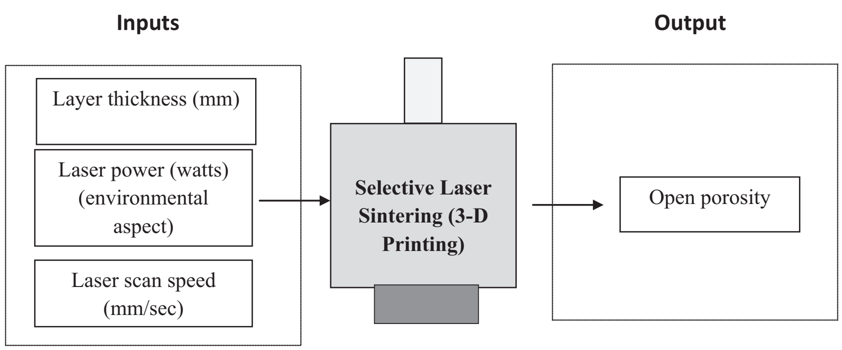

Fig. 1. Problem of modeling of open porosity as a function of environmental input variable.