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An optimization approach of selective laser sintering considering energy consumption and material cost

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ABSTRACT

Selective laser sintering technology is a method of additive manufacturing that is growing with widely application. Due to the increasing tense of energy situation, it is also timely to consider the economic and environmental issues of growth in additive manufacturing. The innovative selective laser sintering technology optimization approach proposed in this article encourages and enables the designers and users to obtain optimal sintering parameters and reduces energy consumption and cost in sintering process. This paper creates a potential approach for realizing the relationship between main sintering parameters and energy consumption and material cost. To achieve high efficiency of the process, optimization of parameters based on energy and cost consumption are investigated. A multi-objective model with optimized constraints is set up and solved by non-dominated sorting genetic algorithm II. Energy consumption and material cost are treated as the two objectives, which are affected by three variables, namely scanning speed, gap distance and layer thickness. The effectiveness of the multi-objective optimization model was verified experimentally and results are fully discussed.

1. Introduction

As a major area for global economy, manufactory is responsible for over one third of global energy consumption and CO_2 emissions (Seow et al., 2016; Garwood et al., 2018). Reducing energy consumption and CO_2 emissions become significant for alleviating the energy and environmental impact. In the past decade, substantial effort has been made to reduce the overall energy consumption and carbon emission in industry, particularly in industry (Tuo et al., 2018; Ma et al., 2017)0. However, the energy consumption of emerging technologies-such as additive manufacturing (AM) is often over looked (Verhoefa et al., 2018). As AM has been applied to a lot of industrial fields, many issues remain to be solved yet at present, including the environmental issues and material issues and its energy efficiency. Three typical processes, stereo lithography apparatus (SLA), selective laser sintering (SLS), and fused deposition modeling (FDM) are the most popular due to their cost and technical performance. SLS was selected as the target of investigation and methods were discussed for exploring the relationship between main sintering parameters and energy consumption and material cost. The entire market of AM products and related services have enjoyed significant growth as shown in Fig. 1 (Yeh, 2014), as it is forecast to grow at an annual rate of more than 20% for recent 5 years, according to the International Data Corporation (IDC).

Compared with traditional subtractive machining methods, AM technologies have a great potential for materials and energy efficiency (Luo et al., 1999). Hence, AM processes are seen as “cleaner” processes, however, its energy consumption far exceeds that of the traditional manufacturing process, as this shown in Table 1 (Hague and Tuck, 2007). So the perception that AM consumes less energy than conventional manufacturing processes may be misplaced and this comes as a shock to researchers.

Following a comprehensive literature review of publication on AM in the past two decades, most of them were concerned with process control (Schoinochoritis et al., 2015)0, cost (Franchetti and Kress, 2017; Raut et al., 2014)0, material (Yadollahi and Shamsaei, 2017; Mower and Long, 2016) 0 and mechanical properties

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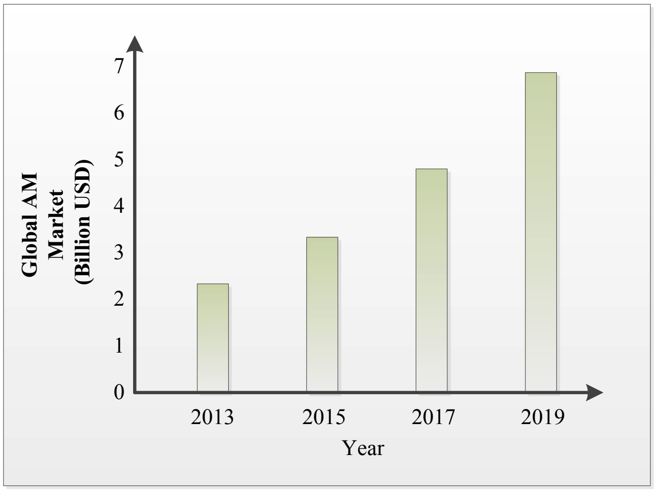

Fig. 1. Global market trend of AM products, material and services.

(Onwubolu and Rayegani, 2014). Furthermore, only few literatures focus on energy consumption and efficiency optimization of AM.

As global warming and shortage of resources become more serious, research on the environment impact and energy consumption of AM should be taken seriously and timely. Gutowski et al. (2009) revealed that new manufacturing processes could work to finer dimensions and smaller scales, but at lower rates, which resulted in very high specific electrical energy consumption. Additionally, Huang et al. (2015) presented a system modeling framework for estimating the net changes in life cycle primary energy and greenhouse gas emissions associated with AM technologies. Burkhart and Aurich (2015) proposed a framework to predict the environmental impact of additive manufacturing in the life cycle of a commercial vehicle.

Numerous scholars adopted the energy consumption rate for the analysis of AM energy consumption characteristics. Sreenivasan et al. (2010) proposed an energy consumption rate for the analyzing sustainability of SLS from three aspects. Tang et al. (2016) integrated a design stage in a product life cycle assessment for minimizing the environmental impact of AM product. Meteyer et al. (2014) presented an energy and material consumption model of binder-jetting process, as well as provided life cycle inventory data for it life cycle analysis. Baumers and Martin, (2012) reported a method for the quantitative analysis of the shape complexity of AM integrated with the evaluating of build time, energy flows and costs. Ahsan et al. (2015) proposed a novel two-step optimization method in which the build orientation for the object and material deposition orientation were considered. Bourhis et al. (2013) described a new method which was based on a forecasting model of energy consumption defined from the manufacturing path and CAD model.

In addition to the above-mentioned research that focuses on environmental assessment of AM processes, some researchers have done a comparative study on the environmental impact of different AM processes. Mani et al. (2014) proposed a measurement framework to compare the sustainability of different AM processes. Yoon et al. (2014) researches on the specific energy consumption (SEC) of three typical types of manufacturing methods, the investigation results show that the SEC of AM processes is 100 times higher than the conventional bulk-forming processes. Baumers and Martin (2012) used a novel segmentation method to segment the energy consumption into four types. And the research result indicates that time-dependent energy consumption is the main energy drain.

Not only AM energy consumption characteristics are different from conventional manufacturing, but different AM technologies are also different. To date, previous studies are significant for the qualitative analysis on comparative advantages in paper, which lack quantitative evaluating theory and method. Deficiencies of previous studies focus mainly on the following two aspects: one is a mere comparison of energy consumption between AM and conventional manufacturing; and one is made some qualitative studies. It is necessary for AM energy consumption to synthetically consider various production requirements or influence factors, but most existing studies only consider cost of the production process using a single objective method without other significance factors such as energy consumption or time. However, the research in this field is only at the starting line because more attention was paid to material and forming technology previously, furthermore the research done from the perspective of energy consumption is likely to arise more over time.

Due to the quality and ease of use of its products in the manufacturing, SLS is the widely used technology in AM (Olakanmi et al., 2015). Considering the future large-scale application, there have been significant potential in improving the energy efficiency and manufacturing cost of sintering process. Nonetheless, few effective methods are available for optimization the energy consumption in AM due to its complexity and variety in energy consumption process, especially metal-based process. SLS is selected for the present study because of the SLS process takes a long time and energy consumption and material consumption rate is high.

According to the author's previous research, it can be found that even if the same type of SLS system processed the same specification workpiece, the energy consumption E (the total energy consumption of the SLS system) may be E_A greater than E_B, or it may be the opposite. Investigate its reasons can from the following aspects thinking: operators are lack of standards and guidelines in printing process, etc. In most cases, setting the process parameters, sintering power, scanning path and other variables by experience, and this leads to a great difference in energy consumption, material consumption, and roughness. Therefore, in addition to taking into account the physical properties of the product, the SLS system needs to consider the economic, environmental characteristics and the coupling characteristics between the three.

Moreover, research on its energy consumption, cost and resource utilization rate can effectively improve the energy efficiency of manufacturing process, in addition, reducing the manufacturing costs and carbon dioxide emissions, and make the manufacturing process more green and economical. Consequently, it is important to forecast the energy use in AM, which will assist

Table 1
Environmental impact for traditional manufacturing versus AM.

Process		Energy use (kg CO_2 per parts)	Water usage (kg per parts)	Virgin material use (kg per parts)
Traditional	Casting	4.3	0.23	2
	Injection Moulding	0.003	N/a	0.01
AM	SLM	13.15	0	0.67
	SLS	0.084	0	0.006