Accepted Manuscript

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PII: S2352-4928(17)30049-1
DOI: https://doi.org/10.1016/j.mtcomm.2018.02.006
Reference: MTCOMM 282

To appear in:

Received date: 28-3-2017
Revised date: 6-2-2018
Accepted date: 10-2-2018

Roadmap to sustainable plastic additive manufacturing

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ABSTRACT
As additive manufacturing (AM) is heading towards mass production and mass customization, the process needs to be environment-friendly and energy-efficient in order to be self-sustainable. Selective laser sintering (SLS) and fused deposition modeling (FDM) are two processes contributing massively towards plastic additive manufacturing. In SLS, the powders that do not contribute to the mass of products become unusable (after some number of reuse) and finally turn into waste. As high energy is required for production of powders, generation of these wastes impacts environment sustainability. A contrivance needs to be developed to convert these waste powders into high-value products to make the process sustainable. FDM has the largest market share in terms of number of AM systems sold and is the most popular for fabricating low-value products. Its usefulness will be further expanded if inexpensive high-value products could be made through this process. In the present work, waste SLS powder is employed to prepare feedstock for inexpensive high-value FDM products, which demonstrates that SLS refuse could be utilized for mass production of FDM feedstock. If two processes (SLS & FDM) will be connected as proposed here, it will make plastic additive manufacturing energy-efficient, self-sustainable, and will contribute to environment sustainability, in general.

INTRODUCTION

Selective laser sintering (SLS) is the best plastic additive manufacturing (AM) process because it can make complex and stronger plastic products with ease in comparison to other processes such as stereolithography, photo-polymer jetting and fused deposition modeling (FDM) [1]. However, it suffers from following limitations bringing a question mark to its sustainability: 1) expensive feedstock material (powder), 2) underuse of powders, and 3) high energy requirement for production of powders. Powders for SLS systems are far more expensive than the general powders available for other processes, it is because for SLS, powders are customized to perform well.

In SLS, a product is made by depositing successive powder layers on a platform and by scanning these layers selectively by a laser beam. The layer deposited covers the whole area of the platform irrespective of the size of a desired product. Consequently, even if a tiny product needs to be made, a large amount of powders is deposited. The powders, which remain on the platform and do not contribute to the mass of the product still go through thermal cycles due to the heat generated by scanning action and attached heaters. This leads to deterioration of the properties of the powders and the property of the product made from them is no longer guaranteed. There are numerous studies conducted on the degradation of polymer powders and its effect on final properties, which has suggested various strategies to mix fresh and used powders to attain required property. Used powders are generally mixed with 30-50% of unused powders, and can be processed a few more times before powders turn into waste [2-5]. Consequently, all procured powders are not used leading to underuse, which challenges the cost-effectiveness of the process. Production of powders requires more energy than producing a bulk material. For producing a product from an SLS system, energy requirement for running a machine is far less than that for producing the powder implying a significant environmental impact of powder bed system caused solely for being a powder specific system.

SLS will become sustainable if the powder wastage could be prevented to reduce carbon footprint and negative impacts on environment. However, the trend is just opposite. Powder manufacturers are producing still more expensive powders which have still lower reusable efficiency. It implies that in coming days, in order to provide still better product properties, their reusability will be of less concern to manufacturers leading to more wastage and environmental woes. In case of mass production and mass customization, this will be further exacerbated. These discarded powders are high-value waste because: 1) these are in powder form and 2) they are relatively clean in comparison to general plastic wastes. These advantages of these powder wastes give an opportunity to find a mechanism, which will exploit these benefits to make a useful product.

Fused Deposition Modeling (FDM) is a material extrusion based AM process in which a product is fabricated by melting polymer based filaments and depositing molten materials on a platform. There are a number of various types of inexpensive FDM systems are available making FDM widely used and understood. Consequently, developing a new material for it will have wider impact. PLA (Poly Lactic Acid) and ABS (Acrylonitrile Butadiene Styrene) are chiefly-used materials in FDM while other materials used which are commercially available are polyimide, polycarbonate, nylon, polyvinyl alcohol, high density polyethylene, polyetheretherketone and high impact polystyrene [6-8]. Mechanical properties offered by these materials are limited implying a need to develop a strong material. Two of the best materials supplied by Stratasys (a company for FDM) [9] are given in Table 1. Table shows properties furnished by samples fabricated in both build orientations: vertical (V) and horizontal (H). ULTEM-1010 is ABS (amorphous polymer) based material while Nylon 12 is nylon (semi-crystalline polymer) based material. Nylon 12 provides higher toughness than ULTEM-1010 implying that for an application requiring higher toughness and strength, semi-crystalline based materials are better and need to be selected for developing a new material. Most of the SLS