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Assessment of tests for use in process and quality control systems for selective laser sintering of polyamide powders

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ABSTRACT

The aim of this study was to identify the optimum set of tests required for quality assurance purposes when selectively laser sintering polyamide powders. Both Nylon 11 and Nylon 12 powders are considered, and the tensile, flexural and impact properties are assessed, together with dimensional accuracy, density and melt flow index (MFI). It is concluded that MFI and strength are key measures, with impact strength the preferred strength measure because of its practicality. The MFI and strength measures may be augmented by assessment of dimensional accuracy and density for particular applications. Additional testing beyond these measures did not provide further significant information with regard to the mechanical integrity or dimensional accuracy of the output from a build.

1. Introduction

Additive manufacturing (AM) is a layer based manufacturing technology that produces parts directly from a 3D CAD model of the part. Originally AM was used for prototyping (concept evaluations and design verifications) but it is increasingly being used to manufacture functional parts. Popular processes for making polymer AM parts include 3-D printing (3 DP), fused deposition modelling (FDM), selective laser sintering (SLS) and stereolithography (SLA).

The SLS process for polymers (Fig. 1) uses a CO_2 laser that sinters selectively a thin layer of powder spread over a platform. A computer directs a laser, through scanning mirrors, over the powder layer, sintering and bonding a new layer of the part (Jacobs, 1996). Once a layer is completed the platform is lowered and a new layer of powder is spread over the previously sintered layer. These processes are repeated sequentially until the part is fully made (Akande et al., 2013). The produced part is then "broken out" from the build area, and the un-sintered powder removed to leave the required parts.

Common practice in polymer based laser sintering systems involves the blending of virgin powder with used powder to reduce cost and increase material utilisation. However, part properties have been shown to later reduce as a result of repeated exposure to heat (Gornet et al., 2002). This results in different chemical and structural properties and consequently lower physical and mechanical properties of the final part. A powder life study was carried out by Choren et al. (2001) by increasing laser power relative to powder age, and it was observed that although an increase in laser power increased most mechanical properties, higher powers with older powders chemically degraded the powder.

Gornet et al. (2002) used an extrusion plastomer to assess powder properties with repeated use. It was observed that after several builds the melt flow rate (MFR) of the polymer decreased with the number of builds, an indication that the polymer was degrading. Lower MFR was also associated with improvement of elongation at break. MFR or melt- flow index (MFI) is defined as the rate of extrusion of a thermoplastic or resin through an orifice of standard dimensions under prescribed temperature and pressure (Astm D1238-10, 2010).

Most of the quality problems that are experienced in SLS are due to material and process parameters. Beal et al., 2009 investigated the effect of laser energy density on mechanical properties of laser sintered parts by varying the laser power and laser beam speed. Laser power was reported to have more influence on den-

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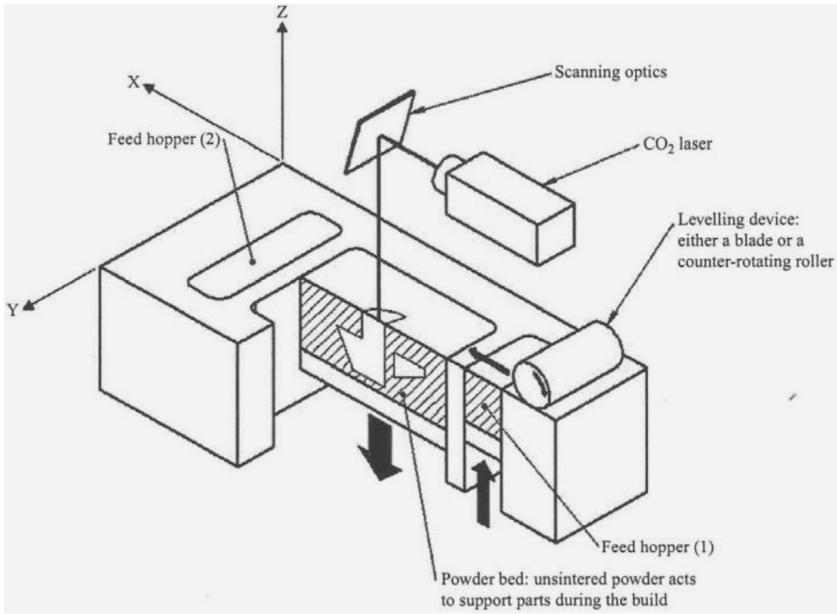

Fig. 1. SLS apparatus showing the principal apparatus directions (Cooke et al., 2011).

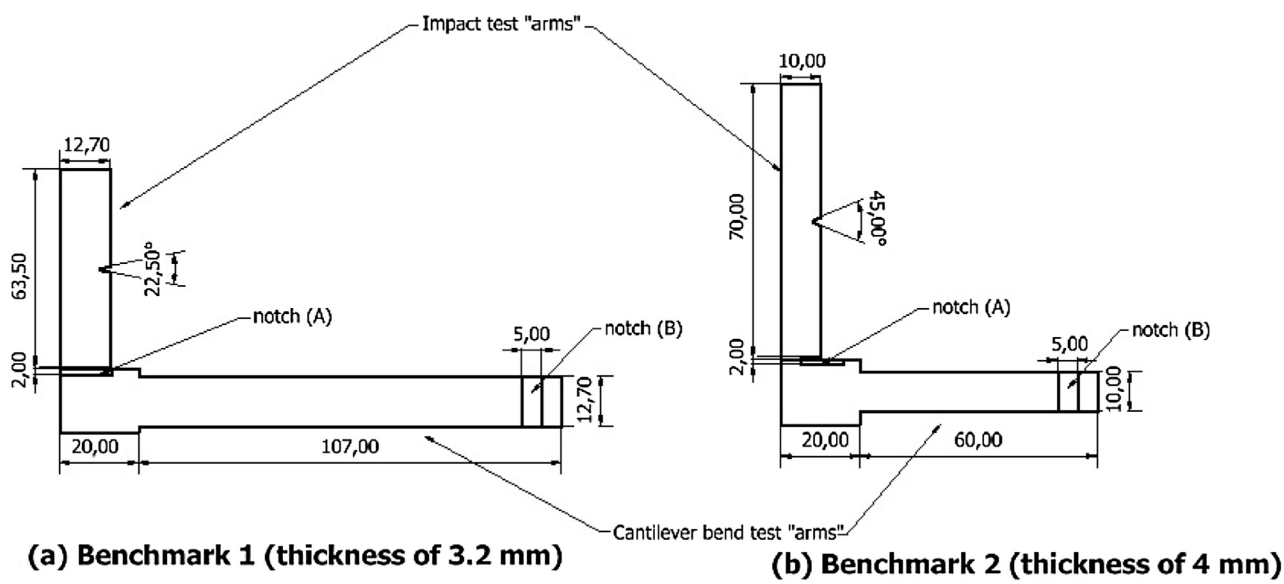

Fig. 2. Benchmark specimens.

sity and mechanical properties of parts than scan speed. Caulfield et al. (2007) also experimentally studied the effects of part orientation and energy density on the physical and mechanical properties of selectively laser sintered parts. Mechanical properties were observed to vary with build orientation. Parts build with low energy density were porous while mechanical properties also tend to increase with an increased in energy density. Ho et al. (2003) examined the effect of energy density on the morphology, physical and tensile properties of sintered test parts. Although, the high energy density was observed to lead to better fusion between powder particles but excessively high energy density also caused an increase in surface roughness, severe curling of the sintered parts and polymer degradation. Ziegelmeier et al. (2014) observed changes in the processing behaviour of powder due to aging during processing cycles in laser sintering process, as well as the mechanical properties of parts made from the powder. But, the inability to guarantee the quality of a part made from SLS is cited as one of the issues holding back the full adoption of the process for manufacturing of end-use parts. Industry requires confidence that manufactured parts will have the required mechanical properties for specific needs (Goodridge et al., 2012). There then exists the need to have a method for monitoring the process and qualifying a build to assure the quality of parts. This paper, therefore, aims at developing a benchmark part to be used in process monitoring and control and for assuring the quality of fabricated parts.

2. Materials and methods

2.1. Testing rationale and requirements for a QA test

Quality assurance (QA) involves resources so there is need to ensure that QA tests are simple, small, reliable, cheap and capable of being carried out quickly (Akande et al., 2013). For practical