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Assessing polymer powder flow for the application of laser sintering

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ABSTRACT

A need exists for techniques to assess flow properties of powders intended for laser sintering (LS). Although several powder flow measurement techniques are available, the flowability of a powder is strongly dependent on the nature of the applied flow field and none of the currently availably techniques adopt the flow field of LS. Therefore, this paper proposes a new technique, which mimics the flow in an LS machine, allowing a more appropriate powder flow evaluation for this particular process. The set-up provides qualitative assessment of powder layer smoothness, as well as a quantitative determination of the packing density of the deposited layer. Measurements on PA12, spherical PS and PMMA, and cryogenically milled TPU powders demonstrate the set-up's capability to evaluate powder flow with regard to LS.

1. Introduction

Due to the complex nature of powders, it is common that different flow measurement techniques, with hence different stress states, yield dissimilar sample classifications [1,2]. Hence, to obtain informative results for a certain application, the chosen technique requires a flow field as similar as possible to the intended application. Here, the application of interest is laser sintering (LS).

LS is a form of Additive Manufacturing, a set of techniques in which parts are built layer-by-layer [3,4]. As a base material, LS uses powders with typical particle diameters of about 50 μm [3,5,6]. The LS machine spreads the powder into thin layers of around 100 μm in thickness. In each layer, a laser sinters the part's cross-section according to a 3D model. The cycle of spreading and sintering repeats until the part is finished [3,6]. It is crucial that the deposited layers are smooth, show no surface defects and preferably have a high packing density in order to reduce the part's porosity [3].

On an industrial scale, the layer quality is often determined by trial-and-error. For the determination of the packing density, which is affected by the powder flow quality, industrial LS machines sinter closed hollow cubes. A weight determination of the enclosed, unsintered powder provides the packing density [7]. This technique, however, requires a large amount of powder and the investment in a fully operational LS machine. To our knowledge, no specific lab-scale testing methods exist to assess the powder flow quality in the sinter process, as was also formulated by Schmidt et al. in earlier studies [8]. The aim of this research is to introduce a useful technique to determine powder flow quality for the laser sintering process.

2. Methods and materials

2.1. Powder spreader

In this work, a new lab-scale powder spreader device is introduced to measure the powder flow quality, particularly for the LS process. The set-up, illustrated in Fig. 1, mimics the layer deposition of a commercial LS machine and assesses the surface quality and packing density. A powder sample is loaded in front of the spreading blade, after which this blade deposits the powder into a thin layer on the measurement plate. The thickness of this layer is imposed by the difference in height between the spreading blade and the measurement plate. Both heights can be adjusted separately, allowing the study of different layer thicknesses, as well as multi-layers. The latter is crucial, as it enables the study of powder-on-powder deposition, which is the type of flow encountered in LS. The measurement plate, measuring 14 cm by 17 cm, rests on a balance. As a result, the balance provides a measurement of the layer weight and, as the layer dimensions are known, the layer density (ρ_{layer}). Dimensions are optimised to provide a sensitive measurement with a minimal amount of sample. Experiments suggest that a scale precision of 0.01 g is adequate to obtain significant measurements.

The set-up is created by the modification of a commercial Elcometer 4340 Motorised Film Applicator. The main adjustments include a

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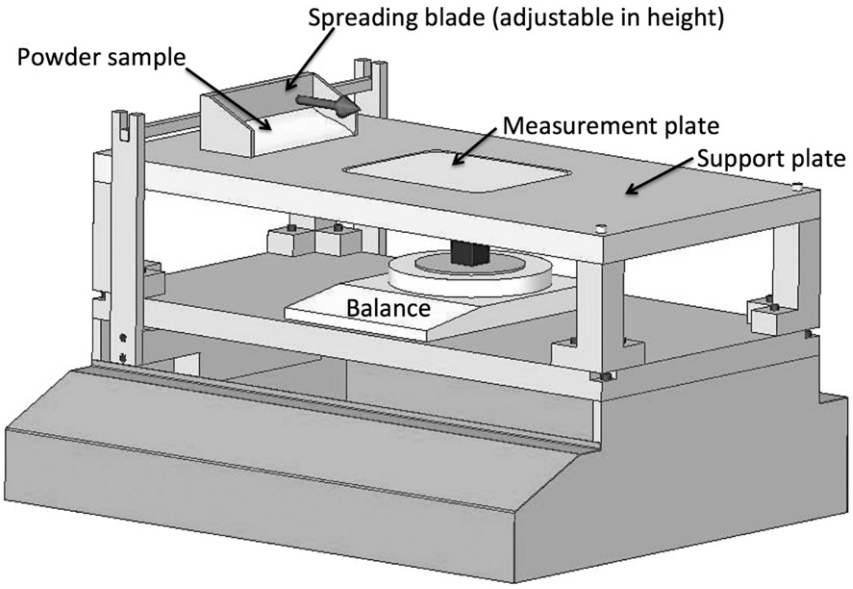

Fig. 1. Schematic illustration of the powder spreader set-up.

support plate for carrying the spreading blade and the aforementioned measurement plate, which rests on the balance. An Elcometer 3580 Casting Knife Film serves as the spreading blade. This applicator consists of a spreading blade, fixed between two blade holders, which rest on the support plate. The spreading blade can be raised or lowered by a micrometre, calibrated at 0 μm where the blade touches the support plate and with a precision of 10 μm, thereby creating a gap of a known height. The set-up however allows the use of other application mechanisms, such as the applicators used in actual LS machines.

2.2. Powder flowability

Both powder flowability and the densest geometrical packing affect the layer density (ρ_{layer}). The better the powder flows, the smaller the particle interactions are, resulting in fewer voids and thus a larger density. ρ_{layer} is directly relevant to the LS process, as a high layer density reduces part porosity, and improves the final part accuracy [9–11]. To exclude the contribution of the material density and thus allow a quantitative comparison of powders of different polymers, a dimensionless packing density, ρ_p, is defined as the ratio of ρ_{layer} and the material density of the polymer (ρ_m).

$$\rho_p = \frac{\rho_{layer}}{\rho_m} \tag{1}$$

The particle geometry and size distribution create a lower limit for the amount of voids. To exclude also these geometrical limitations and look solely at powder flowability, it is useful to define the maximal packing density. Tapping a container of powder approximates the maximal possible packing. During the taps, the particles temporarily lose contact and improve their packing due to reduced friction. This dense packing is referred to as the tapped density (ρ_{tap}) [12]. The ratio of ρ_{tap} to ρ_m thus provides the upper limit for the packing density, limited not by flow, but by geometrical restrictions.

$$\rho_{p,max} = \frac{\rho_{tap}}{\rho_m} \geq \frac{\rho_{layer}}{\rho_m} = \rho_p \tag{2}$$

The ratio of the packing density to its upper limit now provides an index, the packing ratio (PR), which excludes the geometrical limitations as well as the material density and thus only looks at powder flowability. The same ratio is found by dividing layer density directly by the tapped density.

$$PR = \frac{\rho_p}{\rho_{p,max}} = \frac{\rho_{layer}}{\rho_{tap}} \tag{3}$$

Notice the analogy with the Hausner Ratio, a widely used indicator for powder flow $\frac{1}{HR} = \frac{\rho_{bulk}}{\rho_{tap}}$, where ρ_{bulk} is the bulk density of the powder. The indices introduced in Eqs. (1) and (3) are hence not real new indices but rather an adaptation of existing indices to LS. However, the HR utilises the bulk density of a freely poured powder [13]. The flow field thus strongly differs from the forced spreading in LS, which makes the HR less relevant for this application.

Summarised, ρ_p provides a directly useful index for the packing quality of a powder layer in LS. Higher values are preferable, as these lead to denser sintered parts. PR, on the other hand, provides an index that solely evaluates powder flow in LS. As both the geometrical packing and powder flow are relevant, this study reports on both indices.

2.3. Methodology

An experimental protocol is designed to compare the flow behaviour of different powders. Before the actual test, the measurement plate is positioned 1 mm below the upper surface of the support plate. The spreading blade rests on the support plate and the powder is gently poured in front of the blade. The blade is then pushed across the plate at a selected speed, depositing a powder layer on the measurement plate. The first layer serves as a base layer on which subsequent layers are deposited to create conditions similar to those in an LS machine. Moreover, this ensures that any subsequent layers are deposited on a perfectly levelled area.

For the following layers, the blade is raised 100 μm each time, allowing the deposition of a 100 μm layer. An amount of powder, roughly twice the amount needed to form a 100 μm layer, is poured in front of the spreading blade. After the deposition, the balance measures the added weight, which serves as a first data point. This process is repeated, and subsequent layers are spread to gather additional data points. The results are obtained by taking the average over twenty layers. The layer quality is observed visually. The presence of defects is noted, as well as a qualitative indication for the surface roughness.