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Material properties

On the difference in material structure and fatigue properties of nylon specimens produced by injection molding and selective laser sintering

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ABSTRACT

This paper describes the influence of dynamic tension/compression loading on notched and unnotched nylon specimens fabricated by Injection Molding (IM) and Selective Laser Sintering (SLS). The main objective of this work is to analyze and describe the differences in material structure and fatigue properties of as-built nylon parts produced by IM and SLM from the same polyamide 12 powder. The differences in dimensional quality, density, surface roughness, crystal structure and crystallinity are systematically measured and linked to the mechanical fatigue properties. The fatigue properties of the unnotched SLS specimens are found to be equal to those of the unnotched IM specimens. The presence of pores in the sintered samples does not lead to rapid failure, and the microvoid coalescence failure mechanism is delayed. The notched specimens show more brittle failure and increased fatigue resistance which is caused by local notch-strengthening. The results enable improved understanding of the difference in material structure and fatigue behavior of selective laser sintered and injection molded polyamide.

1. Introduction

Selective laser sintering (SLS) is an additive manufacturing process in which layers of preheated powder are spread and laser radiation is used to liquefy (either partially or fully) and fuse the powdered material [1]. Sintered material forms parts, whilst un-sintered material remains in place to support the structure. The build platform is slowly cooled to room temperature after sintering to avoid shrinkage and distortion of the final products. Selective laser sintering has evolved from a rapid prototyping (RP) technique to a promising additive manufacturing (AM) technique. Sintered parts in polyamide are increasingly being used for functional applications in the automotive, aerospace and biomedical industries [2,3]. The SLS process offers a number of advantages over conventional production techniques, such as injection molding (IM): short design to manufacturing cycle time, high geometrical freedom, customized components and inexpensive production of small numbers of parts. However, to be competitive with the conventional production techniques, the mechanical properties of the SLS components must be sufficient to meet in-service loading and operational requirements.

A number of studies have been performed to optimize the mechanical properties using polymer blends [4–8]. Also, the influence of various process parameters such as energy density, cooling rate, scan pattern, layer orientation, delay time, etc. has been analyzed to find an optimal set of production parameters [9–13]. Although the mechanical

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properties of sintered material are of significant importance, very little has been reported in literature on the fatigue properties of sintered polyamide components. Knowledge of the fatigue properties of these sintered materials is limited and accurate fatigue life predictions are, therefore, not possible.

In a previous study, the authors made a first attempt to address this by studying the fatigue failure of unnotched SLS-PA12 components under tension/compression loading [14]. In the present work, notched and unnotched SLS specimens are subjected to the same fatigue loading and compared with notched and unnotched IM specimens. All the specimens were produced from the same powder particles and the quality of the end-products was carefully examined prior to fatigue testing. Consequently, a true comparison between IM and SLS specimens is made.

Fig. 1 shows an overview of the most important parameters influencing the fatigue life of PA12 components produced by selective laser sintering or injection molding. The fatigue life depends on the fatigue testing conditions and the properties of the final parts. These final part properties are functions of the powder quality and process parameters. This work presents a systematic description of process parameters, powder quality and final part properties which is then linked to the experimentally determined mechanical fatigue behavior.

2. Test specimens

2.1. Material and geometry

It is well known that powder properties and dimensions are important for the quality of laser sintered parts. To minimize the influence of the raw material on the mechanical properties of the specimens, one unique batch of semi-crystalline polyamide 12 (PA12) powder was used for the production of the specimens with both SLS and IM. Fig. 2 shows a scanning microscope observation of these powder particles indicating the semi-spherical geometry with average diameter of 60 μm.

Fig. 3 shows the geometry of the notched and unnotched cylindrical specimens that were used for the fatigue experiments. The geometry of the test specimens was chosen according to ISO1352 (rotating bar bending fatigue testing) so that the parts could be subjected to fluctuating bending and torsion stresses in a multi-axial fatigue test rig designed at KU Leuven [15]. Using finite element analysis, the geometrical stress concentration factors were calculated to be 1.02 for the unnotched geometry and 2.12 for the notched geometry.

2.2. Selective laser sintering

Selective laser sintering was used to produce 80 cylindrical test specimens from semi-crystalline polyamide 12 powder. To study the influence of the scanning direction on the mechanical properties, two different orientations were produced. Both the notched and unnotched specimen geometries were manufactured with longitudinal axis along the scan-direction (x) and with longitudinal axis perpendicular to the scan direction (x), as indicated in Fig. 4. In the first case (A), parts are built up layer by layer along the z-direction, and the scan direction corresponds with the loading direction. In the second case (B), parts are also built up in the z-direction but the scan direction is perpendicular to the loading direction.

Table 1 shows the SLM process parameters used in a previous study by Van Hooreweder and also used in this work [14]. With these parameters, high quality test specimens with absolute densities above 0.95 g/cm^3 can be produced and the results can be compared to previous work. To minimize scatter in the mechanical properties, all the specimens were manufactured using the same CO_2-laser powered EOS P730 sinter station. Furthermore, all specimens were built at the same location in the build platform to guarantee equal cooling conditions after the

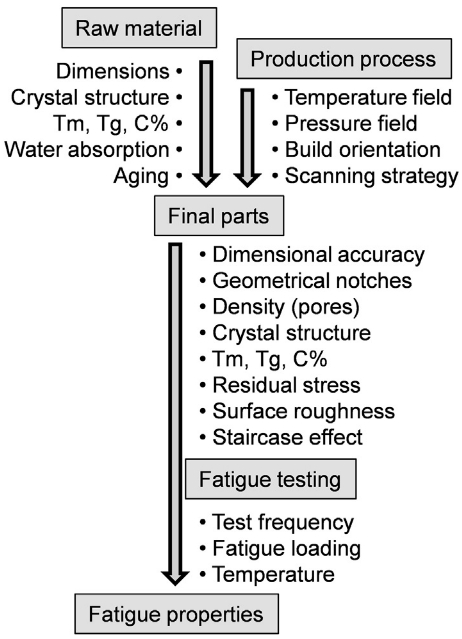

Fig. 1. Overview of parameters influencing the fatigue life of SLS and IM components.

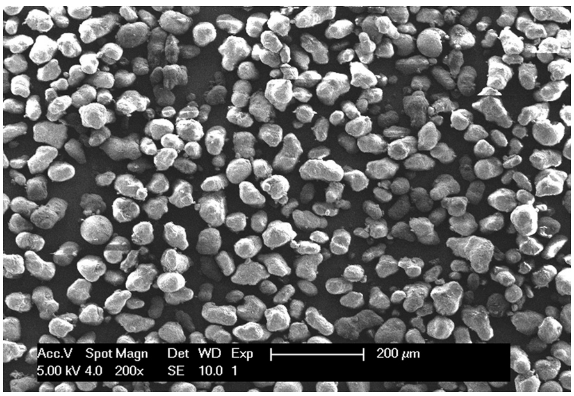

Fig. 2. SEM observation of PA12 powder particles.