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Evaluation of suitability of polypropylene parts manufactured via SLS for spare part applications

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Abstract

The production of spare parts can be adapted to distribute supply chains with Additive Manufacturing (AM) and can be carried out without molds. In the home appliances sector, the production of spare parts by AM has gained importance in recent years. However, the suitability and sustainability of the parts produced by AM for use in the final product are of critical importance. In line with this scope, the suitability of the parts produced with polypropylene (PP) powder with Selective Laser Sintering (SLS) technology for use as spare parts was examined in accordance with the determined criteria. In this direction, samples were produced via both the SLS method and the injection molding (IM) method using PP powder. In addition, the effects of the build direction and the sealing post-process were also examined for the parts produced with SLS. The mechanical properties, surface roughness, surface contact angles and water impermeability of these samples were investigated. It was observed that PP parts produced with SLS have a hydrophobic surface, do not leak water even at 0.7 mm wall thickness and they are less ductile under uniaxial tensile force.

Keywords: Selective laser sintering, Polypropylene, Spare parts, Sealing post-process, Home appliances.

1. Introduction

Additive manufacturing (AM) has been highlighted as a potential method of producing spare parts with the advantage of fast delivery without the need for large inventories. The use of AM for spare parts manufacturing has the potential to be beneficial in businesses where late delivery result in penalties or severe consequences [1]. When considering AM, SLS (compared to other AM technologies) gives the best results for high-volume production under certain conditions [2].

Due to various benefits over alternative polymer AM, the SLS process is widely used. The unfused powder which is surrounding the part acts like a mold. Thus, support structures do not required for this technology. Since there is no binder and support is required, post-processing is also more simple; and a variety of materials, from polyamides to polyetheretherketone, can be processed using this technology [3]. The mechanical properties of the parts produced in the SLS process show anisotropic behavior and the highest mechanical values are obtained in the "flat" orientation, while the lowest values are obtained in the "vertical" [4] production orientation shown in Fig. 1.c.

Polypropylene (PP) is a crucial semi-crystalline thermoplastic because of its outstanding mechanical performance and chemical stability, as well as its low density and cost. There is a rising number of applications in automotive, electrical instruments, textile industry, and other fields. Zhu et al. [6] investigated that SLS manufactured PP parts are less ductile than Injection Molding (IM) manufactured ones. They also studied crystallization behavior of the PP and the resultant microstructures. This paper also investigates the mechanical properties but moreover; watertightness and surface properties of the SLS manufactured PP are also explored. Eventually, findings are evaluated for the suitability of PP manufactured via SLS for spare parts applications.

2. Material and methods

In order to see the effects of the manufacturing technology, PP powders (PP01) from AM POLYMERS GmbH were used in both IM and SLS processes. These PP powders are specially developed for SLS applications. In both SLS and IM, refreshed powders are used with 33% virgin, 33% used, 33% overflow ratios. The DTM Sinterstation 2500+ SLS system was used for the SLS experiments. Flat blade is used instead of a roller as a powder spreading system. The highest sintered part density was 0.86 g/cm^3, with an energy density of 0.13 J/mm^3. The builds in this study were carried out at an energy density of 0.13 J/mm^3 with 0.1 mm layer thickness and at an average part bed temperature of 121^{0}C. All samples are sand blasted after the SLS fabrication.

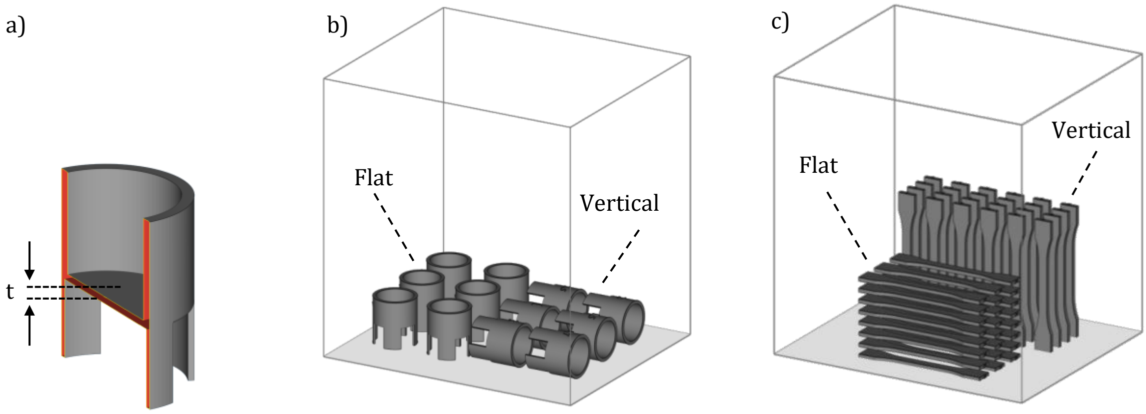

Fig 1. a) Cup design for the leakage test b) build packet of the cups c) build packet of the tensile test specimens.

There are two builds done: one for tensile test specimens (Fig. 2.c.) and the other for the leakage test specimens (Fig. 2.b.). For the leakage test, a cup designed with the dimension of 50 mm outer diameter, 43 mm inner diameter and 30 mm height. The bottom thickness (t) of the cup was designed as a variable and the following values were used (Fig. 1.a.): 0.7 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm. The sample in which the bottom of the cup was positioned parallel to the ground was called "flat", and the specimen in which it was positioned perpendicular to the ground was called "vertical". Thus, a total of 6 "flat" and 6 "vertical" cup samples with varying bottom thickness for each were produced. In each of these cups, 40 gr. tap water was filled and left to stand for 48 hours.

The IM specimens for tensile testing were prepared using an ENGEL injection molding machine. The injection pressure was set to 80 bar, the holding pressure to 65 bar, the temperature setting from the hopper to the nozzle to 160–200 ^{0}C, and the injection speed to 70 mm/s. Tensile tests were done after more than 24 hours of IM process.

The tensile properties of the samples were examined using specimen type 1B, according to ISO 527–2 standard test on a Zwick Z020 universal testing machine. Tensile tests were carried out with 6 sample replicates at room temperature. Tensile test samples were produced in "flat" and "vertical" orientations to observe the lowest and highest mechanical values that may depend on the build orientation. Some of the samples produced with SLS were sealed with Diamant Dichtol WFT (1532) sealing agent. This sealing agent is chosen because it can be used in food contact applications. The sealing process was carried out by immersing the samples in the sealing agent and keeping them for 1 hour. Tensile tests were performed 48 hours after the samples were sealed. The prefix "sealed" was added to the names of the sealed SLS samples.

A non-contact optical surface profilometer (Contour GT-K, Bruker Inc., USA) was used to measure the surface roughness of samples, average value of three randomly selected areas of each sample was recorded. The influence of the build direction, sealing and manufacturing technology on the contact angle of water with the surface of the samples was assessed using an Attension Theta equipment (Attension Theta, Biolin Scientific, Gothenburg, Sweden). The findings were analysed using OneAttention software to determine the surface's wettability. Measurements were performed in triplicate.

3. Results and discussion

There is no water leakage observed on any cup after 48 hours waiting time. The uniaxial tensile test results of the specimens are given in Table 1. The samples produced via SLS were examined within themselves, the Elastic Modulus (E) of the samples produced in the vertical orientation is 10% lower, the tensile strength (σ_{max}) is 7% lower, the yield strength(σ_{yield}) is 10% lower compared to the flat samples. It was observed that elongation at yield (ε_{yield}) is 53% lower and elongation at the break (ε_{break}) is 75% lower in the vertical orientation compared to the flat orientation. The elongation at yield and elongation at break of the samples produced in the vertical orientation were measured at the same values. It was observed that the sealing resulted in a 6% increase in the elastic modulus of the samples produced in both orientations with SLS, and a 5% increase in the tensile strength and yield strength of the samples produced in the flat orientation. Apart from these, no significant effect on mechanical properties was observed. The tensile strength of the samples produced with SLS in flat orientation was 20% higher than those produced with IM, and the yield strength was measured very close to each other. It was observed that the elastic modulus of the samples produced in the flat orientation with SLS was almost the same as IM, while the samples produced in the vertical orientation were 10% lower than the samples produced in IM. The elongation at yield of samples produced in the flat orientation with SLS was 25% higher than the ones produced with IM, but the elongation at the break was 95% less.

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Table 1. Uniaxial tensile test results of IM, SLS and sealed SLS samples.

Specimen	E, MPa	σ max, MPa	σ yield, MPa	ε break, %	ε yield, %
Flat	737±29	20.5±0.2	21±0.3	26±5	15±0.7
Sealed Flat	784±34	21.5±0.3	22±0.4	24.5±3	14.5±0.5
Vertical	659±38	18.7±0.5	18.7±0.5	7±0.5	7±0.5
Sealed Vertical	700±49	19.5±0.5	19.5±0.5	7±0.8	7±0.8
IM	731±38	17±2.5	22±1	619±49	12±0.4

The porous structure of the parts produced with SLS is thought to be one of the most important reasons of this result. The materials' surface characteristics were assessed. Fig. 2 depicts the contact angle of water with the material surface. For each sample, an example image is given in Fig. 2.I. It was observed that the contact angle of the un-sealed flat and vertical samples produced with SLS was 108±5.2 ^{0} and 116±6.2 ^{0}, respectively. It can be said that PP samples produced with SLS are hydrophobic due to their contact angles above 90 degrees. It was observed that the PP samples produced with IM were also hydrophobic, which was measured as 97±1.8 degrees contact angle.

The surface roughness map of the produced samples obtained by optical profilometer is shown in Figure 3.I. The roughness of the underlying surface of the samples produced in flat orientation with SLS was measured as an average of 11 µm. On the upper surface, it was measured as 13.9±0.9 µm. The results of the surface roughness, Ra, measured by optical profilometer, are as shared in Figure 3.II. The results of the upper surface of flat samples are shared in these graphs and images. It was observed that the surface roughness of the samples produced in vertical orientation was 19.7±0.4 µm, that is, higher values than the flat samples. It is necessary to consider that the related productions are carried out at a layer height of 0.1 mm and that the surface roughness in vertical orientation can give different values at different layer heights. No effect of the sealing on the surface roughness was observed.

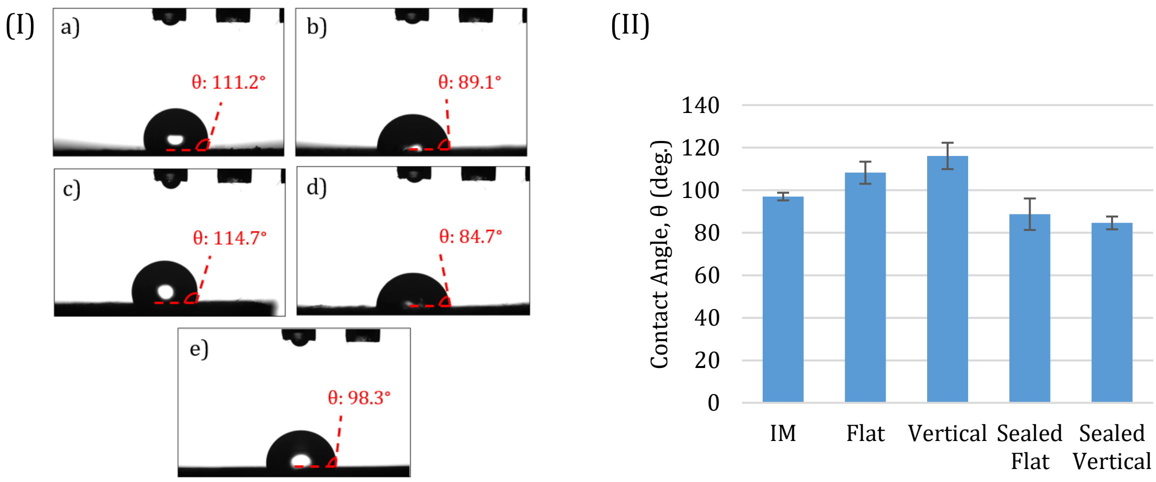

Fig 2. (I) Contact angle measurement images of; a) flat, b) sealed flat, c) vertical, d) sealed vertical, e) IM specimens. (II) Average contact angle results.

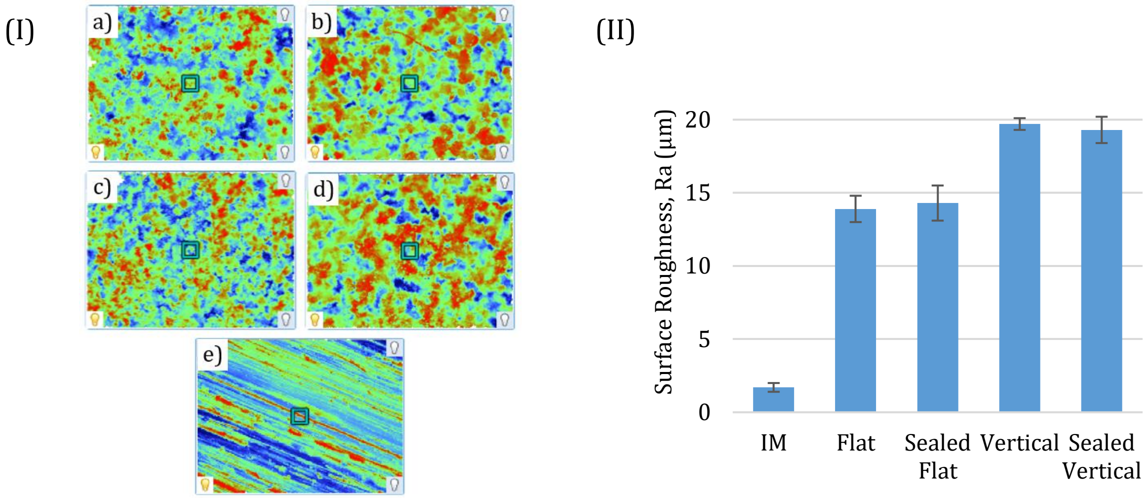

Fig 3. Optical surface profilometry images of; a) Flat, b) sealed flat, c) vertical, d) sealed vertical, e) IM specimens. (II) Average surface roughness measurement results.

4. Conclusions

In this study, the mechanical properties, surface properties, water tightness of the parts produced from PP material with the SLS process were examined in order to evaluate the usability as spare parts and compared with the samples produced with PP using the IM process. Diamant Dichtol sealing agent, which was tried to improve the properties of the parts produced with SLS, was not observed to improve anisotropy in mechanical properties. It was determined that the limiting point to be considered in the case of producing spare parts from PP material with SLS is the elongation at break in terms of mechanical properties. In applications where elongation is critical, the production of parts in flat orientation should be considered. As long as PP parts produced via SLS do not undergo plastic deformation, they can simulate PP parts produced via IM. However, after plastic deformation, they fracture at much lower elongations than the parts produced with IM and exhibited different behavior. PP parts produced with SLS did not leak water even at 0.7 mm wall thickness. As a result of the contact angle measurement test, it was observed that the PP parts produced with SLS have a hydrophobic surface. According to the optical surface profilometer measurement results, if the PP parts produced using SLS are to be used on surfaces in contact with each other, it will be useful to consider that the surface roughness is in between 13-20 µm. In future studies, the suitability of different filled and unfilled thermoplastics for spare parts will be examined with the same systematic. Furthermore, it is aimed to expand the range of applicable spare parts by examining watertightness under different pressures.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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