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Abstract

Understanding Dimensional and Geometrical Tolerances of Metal, Polymer and Composite Powder-Bed Fusion Additive Manufacturing Technologies †

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Powder-bed fusion (PBF) additive manufacturing technologies have the potential to produce near-net shaped complex final parts for various industries, such as aerospace and automotive. However, in some cases, geometrical features and tolerance requirements may prevent these technologies from being employed in more demanding applications. In this sense, the analysis of basic geometrical features, such as cylinders, holes and thin walls, and steps of a test artifact design by the National Institute of Standards and Technology and manufactured by PBF technologies is presented. The main goals are (i) to compare the dimensional tolerances of different test artifacts produced by PBF with different materials (aluminium, polyamide 12 (PA12) and PA12, incorporating multi-walled carbon nanotubes (MWCNT)), (ii) to understand the influence of processing parameters (viz., energy density supplied on polymeric PBF of PA12) and (iii) to study the effect of different weight percentages of MWCNT incorporation on the PA12 polymeric matrix on dimensional and geometrical accuracy of additively manufactured complex parts. In all cases, the manufactured test artifacts were evaluated through computed tomography (CT) scanning and the main dimensional and geometric features were determined using an inspection software.

The results showed that, regardless of the PBF system and material used, holes, cylinders or thin walls with diameters or thicknesses less than 0.5 mm were not produced and parallelism was the most critical geometrical parameter under study. However, test artifacts produced with PA12 and PA12 incorporating MWCNT did not even exhibit holes with a nominal diameter below 2.0 mm, ensuring a maximum tolerance of ±0.1 mm.

With regard to the influence of processing parameters on PBF of PA12 material, the results revealed that medium-low values of energy density supplied during the sintering were advantageous to produce holes, while medium-high values were advantageous for the manufacturing of thin cylinders in upward-facing surfaces. The average deviation in the xy-positioning of cylinders also showed critical dependence on fundamental laser-sintering parameters. The flatness, straightness and parallelism of surfaces were the geometrical parameters that mostly increased with the energy density.

The CT scans also revealed the significant impact of different weight percentages of MWCNT incorporation on the dimensional and geometrical accuracy of complex parts.

This reinforcement incorporation used to enhance the mechanical and electrical properties negatively influenced the quality of surfaces and geometrical features, depending on the weight percentage applied. Besides the increase in parallelism and flatness, test artifacts produced with minimum amounts of MWCNT revealed thin cylinders up to 0.5 mm of nominal diameter, contradicting the minimum size of 1.5 mm achievable in test artifacts produced with higher amounts of MWCNT.

In resume, this research proved that the dimensional and geometrical accuracy of parts produced by PBF systems depends on the process itself, material and process parameters selected for the sintering. For this reason, an in-depth understanding of the most relevant effects caused by these factors allows for an earlier control of the accuracy of PBF parts in order to guarantee the fulfilment of technical requirements for advanced applications. Furthermore, by demonstrating the process and material dimensional limitations, this research improves the knowledge in design for additive manufacturing (DfAM), based on the specific equipment and materials that researchers are designing for.

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