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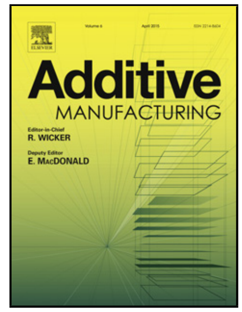

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A Semi-Analytical Thermal Modelling Approach for Selective Laser Melting

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Abstract

Selective laser melting (SLM) wherein a metal part is built in a layer-by-layer manner in a powder bed is a promising and versatile way for manufacturing components with complex geometry. However, components built by SLM suffer from substantial deformation of the part and residual stresses. Residual stresses arise due to temperature gradients inherent to the process and the accompanying deformation. It is well known that the SLM process parameters and the laser scanning strategy have a substantial effect on the temperature transients of the part and henceforth on the degree of deformations and residual stresses. In order to provide a tool to investigate this relation, a semi-analytical thermal model of the SLM process is presented which determines the temperature evolution in a 3D part by way of representing the moving laser spot with a finite number of point heat sources. The solution of the thermal problem is constructed from the superposition of analytical solutions for point sources which are known in semi-infinite space and complimentary numerical/analytical fields to impose the boundary conditions. The unique property of the formulation is that numerical discretisation of the problem domain is decoupled from the steep gradients in the temperature field associated with laser localised heat input. This enables accurate and numerically tractable simulation of the process. The predictions of this semi-analytical model are validated by experiments and the exact solution known for a simple thermal problem. Simulations for building a complete layer using two different scanning patterns and subsequently building of multiple layers with constant and rotating scanning patterns in successive layers are performed. The computational efficiency of the semi-analytical tool is assessed which demonstrates its potential to gain physical insight in the full SLM process with acceptable computational costs.

Keywords: Additive manufacturing, SLM, cost efficient thermal modelling, scanning strategy, semi-analytical model

1. Introduction

Additive manufacturing (AM) also known as '3D printing' is the generic name for building three dimensional objects by way of laying down successive thin slices of the object in a layer-by-layer manner [1]. This is contrary to conventional manufacturing techniques involving multiple steps where the final shape of the component is achieved, for instance, by casting, forming, and material removal. AM processes are rapidly advancing and thus enable fabrication of complex components with high topological freedom within a single manufacturing step. The unique advantage of AM is that, as the geometrical complexity of the object increases, no additional process time or cost get introduced [1].

Selective Laser Melting (SLM) is the most common AM technique suitable for producing metal parts. In SLM, the build process of the product starts on a metal base plate placed inside an inert atmosphere as illustrated in Fig. 1. A thin layer of powder, typically having a thickness of 20 to 100 μm [2, 3], is spread with a recoater blade across the build area. Next, a focussed laser beam, having an energy sufficient to locally melt the metal powder, is directed onto the powder bed with a scanning mirror. The laser beam is scanned over the powder bed in such a way that it selectively melts and fuses powder particles to form the cross-sectional slice of the product upon solidification. The surrounding powder which has not been irradiated with the laser beam remains loose and serves as a support for the subsequent powder layers. Next, the build platform is lowered for a distance equal to the powder layer thickness and a new layer of powder is laid and levelled with the recoater blade. The laser beam scans the subsequent slice. While the laser scanning is applied, in addition to the powder layer, the previous solid layer is also partially locally melted so that during subsequent solidification, a seamless connection across the layers is achieved [4]. The process is repeated until the complete three dimensional object is built, typically consisting of hundreds of layers. If any of the layers is unable to sufficiently support the next one, support structures may be required to eliminate overhanging. Support structures also prevent overheating and restrict deformations. However, they increase the build time and material cost. Finally, the object is cut from the base plate and support structures are removed, loose powder is cleaned off and optionally a final finishing process is performed [3].

SLM can produce parts with densities up to 99.9% of the theoretical density [5] (i.e., with virtually no porosity) and mechanical properties similar to those produced by conventional manufacturing techniques [5, 6]. Although SLM parts exhibit a surface waviness, critical for cyclic loading, high surface quality can often be achieved with a finishing process [7, 8]. More-

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