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Direct selective laser sintering/melting of high density alumina powder layers at elevated temperatures

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Abstract

Direct selective laser sintering (SLS) or selective laser melting (SLM) are additive manufacturing techniques that can be used to produce three-dimensional ceramic parts directly, without the need for a sacrificial binder. In this paper, a low laser energy density is applied to SLS/SLM high density powder layers of sub-micrometer alumina at elevated temperatures (up to 800°*C*). In order to achieve this, a furnace was designed and built into a commercial SLS machine. This furnace was able to produce a homogeneously heated cylindrical zone with a height of 60 mm and a diameter of 32 mm. After optimizing the layer deposition and laser scanning parameters, two ceramic parts with a density up to 85% and grain sizes as low as 5 μm were successfully produced.

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1. Introduction

Ceramic material is conventionally processed through a powder metallurgy (PM) process, consisting of (1) powder production, (2) primary shaping, (3) de-binding, (4) furnace sintering and (5) final shaping. This is summarized in figure 1. Primary shaping is traditionally done by slip casting or injection moulding. However, recent developments in additive manufacturing (AM) technologies have made it possible to shape ceramic parts in geometries and forms that cannot be achieved by the traditional techniques. Laser based rapid manufacturing technologies, like selective laser sintering (the laser beam partially melts the powder particles, SLS) or selective laser melting (the laser beam fully melts the powder particles, SLM), are very promising in this area and could perform the primary shaping step in the PM process for small series of complex parts. Two different types of selective laser sintering (SLS) can be distinguished: indirect SLS (iSLS) and direct SLS (dSLS).
In iSLS, ceramic powder is mixed with a polymer binder. The resulting powder can be used as such (dry) or suspended in a liquid to obtain a slurry (wet). The dry powder or slurry is then deposited and laser scanned layer by layer. The laser scanning melts the polymer binder, 'glueing' the ceramic particles together in the process. The sacrificial

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polymer binder is then removed from the green part during the de-binding process. Finally, the resulting ceramic part is sintered in a furnace. Subramanian et al. (1995) performed iSLS on an alumina/polymer powder system and produced alumina parts with densities up to 50 % and strengths of 8 MPa. A decade later, Liu et al. (2007) used ball-milled mixtures of alumina and stearic acid to manufacture ceramic bars with densities up to 88 % and flexural strengths of 255 MPa. Leu et al. (2012) performed iSLS on zirconium diboride powders mixed with stearic acid binder to produce ceramic parts with average densities of 87 % and average flexural strengths of 250 MPa. The iSLS process can be combined with post-processing techniques to further increase densities and improve final mechanical properties. Typical post-processing techniques are isostatic pressing (Liu et al. (2013)) and infiltration (Shahzad et al. (2013)). Recently, slurry-based iSLS processes are being chosen over powder-based variants. Tang et al. (2011) proved that alumina ceramic parts with densities up to 98 % and average flexural strengths of 363.5 MPa can be produced by performing iSLS on a slurry composed of alumina powder coated with polyvinyl-alcohol (PVA). It appears that slurry-based processes (which are colloidal processes since the slurries consist of ceramic particles smaller than 1 μm) can produce highly dense ceramic parts more easily.

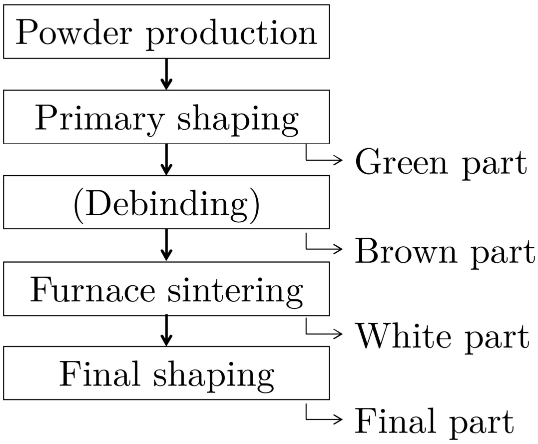

Fig. 1: The PM process.

In direct SLS/SLM, no polymer binder is used. The ceramic particles are deposited and laser scanned layer by layer. The interaction of the laser with the ceramic particles will cause the particles to bind together if the applied laser energy density is sufficiently large. Afterwards no de-binding or furnace sintering is required. Bertrand et al. (1997) investigated the influence of powder characteristics and direct SLS/SLM process parameters on the final properties of zirconia parts. They were able to produce zirconia parts with densities up to 56 %. Wilkes et al. (2013) combined SLM of zirconia-alumina powders with preheating temperatures of up to 1800°C. In this way, ceramic objects with near 100 % density and flexural strengths up to 538 MPa were made. However, the surface quality and dimensional accuracy were poor.

In this paper, high density powder layers are deposited through electrophoretic deposition (EPD) of a ceramic slurry (colloid). High preheating temperatures (800°C) are combined with direct SLS/SLM to rapidly produce three dimensional alumina parts. The EPD layer deposition combined with high preheating temperatures ensured that only a small laser energy density was necessary to fuse the alumina particles together. In this way, large grain sizes and high thermal gradients could be avoided.