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Strategy of manufacturing components with designed internal structure by selective laser melting of metallic powder

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Abstract

Application of selective laser melting for manufacturing three-dimensional objects represents one of the promising directions to solve challenging industrial problems. This approach permits to extend dramatically the freedom of design and manufacture by allowing, for example, to create an object with desired shape and internal structure in a single fabrication step. The design of the part can be tailored to meet specific functions and properties (e.g. physical, mechanical, chemical, biological, etc.) using different materials. Metallic objects were manufactured by Phenix PM 100 machine from Inconel 625 powder. The objective was to analyze the influence of the manufacturing strategy on the internal structure and mechanical properties of the components manufactured by selective laser melting technology. Anisotropy of the internal structure and mechanical properties of the fabricated objects were studied.

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Keywords: Rapid manufacturing; Selective laser melting; Powder

1. Introduction

Nowadays, selective laser melting (SLM) technologies are widely used in space, aviation, automotive and other industries. This technology offers a range of advantages compared to conventional manufacturing techniques: shorter time to market, use of inexpensive materials, higher production rate, versatility, high part accuracy, ability to produce more functionality in the parts with unique design and intrinsic engineered features. SLM technology makes it possible to create fully functional parts directly from metal powders without using any intermediate binders or any additional processing steps after the laser sintering operation. Combination of such mechanical properties as plasticity and toughness with significant strength, hardness and elasticity is of a key importance for metal components manufactured by SLM technologies. These properties depend not only on composition and size of the initial powder particles, but also on the internal structure design and the presence of defects in the final product that are determined by the process parameters and manufacturing strategy [1–3].

2. Experimental procedure

In this study the SLM machine PM 100 (Phenix Systems) was used. PM 100 machine has the typical design for SLM equipments [4,5] and allows to manufacture parts from metallic and ceramic powders within a cylindrical volume of 100 mm diameter and up to 100 mm in height. The source of radiation is a YLR-50 cw fiber laser manufactured by IPG Photonics with a maximum power $P = 50$ W, the wavelength $\lambda = 1075$ nm and the laser spot size $d \sim 70$ μm.

At the given laser parameters the optimum thickness of the powder layer layered by a roller is 20–60 μm. A further increase in layer thickness leads to the drops formation that results in a considerable deterioration of product quality [6]. After laser scanning of each layer, the manufacturing plate is lowered by the thickness of the layer to be deposited thus keeping the surface in the focal plane.

The difference of PHENIX approach in comparison to other manufacturers is the use of a wide range of commercially available powder. In the present experiments Inconel 625

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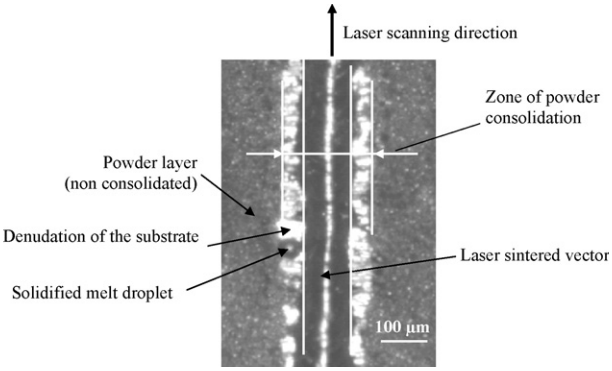

Fig. 1. Laser sintered vector from Inconel 625 powder on steel substrate (thickness of powder layer is 50 μm) for $V = 0.13$ m/s.

powder was used. The composition is the following: Ni (balance), Cr (22.0%), Fe (5% max), Nb (3.5%), Mo (9.0%), Al (0.4% max), Ti (0.4% max), C (0.1% max). The powder size distribution was studied using a granulo-morphometer ALPAGA 500NANO (OCCHIO s.a.). Powder particles were mainly spherical and 95% of them had a size less than 20 μm. Inconel 625 alloy exhibits excellent corrosion resistance to many severely corrosive environments.

The tests of fabricated samples were carried out on equipment INSTRON, power 30 kN, class 0.5 (NF-EN-10 002-2 equivalent to ISO-7500/1), 0.5% accuracy of the read value and monitored by the 4-markers method of Vidéotraction®. The strain was applied at a rate of 1 mm/min at 23 °C.

3. Results and discussion

The influence of such technological parameters as laser power and laser scanning velocity was studied previously [6]. The present paper was aimed to study the influence of the hatch distance (offset between two neighboring melted tracks) on internal structure and porosity of the samples. The following set of hatch distances was used: 60, 80, 100, 120, 140 μm.

Hereafter, a line of remelted powder will be referred as a ‘‘vector’’. At laser power 50 W, laser spot diameter 70 μm, scanning speed 0.13 m/s and powder layer thickness 50 μm, the width of an individual vector is about 120 μm, i.e. a track of consolidated powder is larger than the laser spot diameter. Besides, denuded from powder zones of about 30 μm appear on the substrate (or on the previous remelted layer) on both sides of the vector. At a hatch distance less than 120 μm a partial second remelting of the previous vector occurs. Because of the fact that track of consolidated powder is larger than the laser spot size (Fig. 1), after a certain number of vectors breaks appear in the remelted layer. This results in a repetitive fault in the subsequent SLM cycle and, therefore, in a defective porous structure. At a hatch distance of 60 μm (Fig. 2a), the cross-section of the sample represents a regular structure with pores. The angle of slope α of the pore chains on the laser scanning planes is about 50° (Fig. 2c), porosity of the samples is about

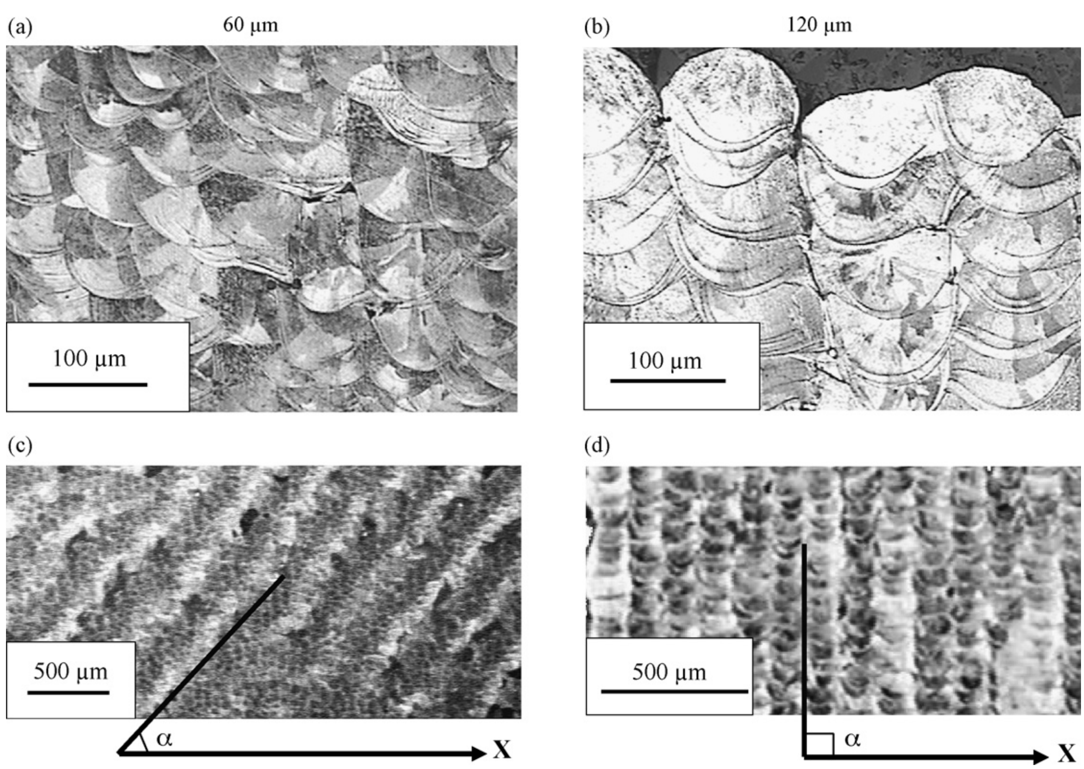

Fig. 2. Cross-section of the sample at hatch distance 60 μm (a, c) and 120 μm (b, d). Vectors are oriented perpendicularly to the cross-section plane. View of the cross-section geometry of individual vectors (a, b). View of the anisotropic structure of the manufactured samples; angle α is measured between the scanning direction (X) and the direction of elongation of the regular structure columns (c, d).