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Characterization of Microstructure and Mechanical Properties of Direct Metal Laser Sintered 15-5 PH1 Stainless Steel Powders and Components

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Abstract

15-5 PH1 stainless steel powder is one of the common materials used for the DMLS process. In this study, both the powder and parts fabricated via DMLS have been characterized. The microstructure and elemental composition have been examined. The microhardness and surface roughness have also been measured. The results show that most powder particle are in spherical with a particle size of 5 ~ 60 μm. Chemical compositions of the powder compare well with the literature data. The thickness of rough surface is about 1 μm. The measured Rockwell hardness is HRC 42.9±0.3, which is also in good agreement with literature.

Introduction

Direct metal laser sintering is an additive manufacturing technique that uses a laser as the power source to sinter powdered metal material, aiming the laser automatically at points in space defined by a 3D model, binding the material together through sintering process to create a solid structure [1]. An important group of metals using DMLS technique is stainless steel [2], which has a broad applications in medical and structural fields [3].

This study is focus on powder characterizations of the 15-5 PH1 stainless steel powders and parts through a variety of techniques to provide fundamental data for processing improvements. The characterization techniques include scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), atomic force microscope (AFM), and Rockwell microhardness.

Experimental

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Particle size and particle shape/morphology are the most important characteristics for powders. Microstructural images of the powder have been taken by using a field emission scanning electron microscope (FESEM, JEOL 7800F), using an acceleration voltage of 5 kV, with electron beam current of 18 nA. The magnification of the SEM images is in the range of from 200 to 5000. In order to get the composition information of 15-5 stainless steel powder, an energy-dispersive X-ray spectroscopy (EDS) analysis was conducted. Additionally, atomic force microscopy (AFM) was used to measure the surface roughness of the printed parts.

Results and discussion

15-5 stainless steel powders

The SEM images of the EOS 15-5 PH1 stainless steel powders are shown in Figures 1 and 2. As shown in Figure 1, the powders are mostly spherical. Some of the powders (< 30%) are ellipsoid, and very few (< 5%) are in irregular shapes. Particle sizes are in a range of 5 - 60 μm, which indicates that there is a powder particle size distribution. Several bonded powder pairs are visible, with neck between them, which is commonly observed in powder atomization or sintering process. Another cause may be due to some of the powders are partially recycled during previous DMLS process. In Figure 2, high magnification image reveals the surface texture of the particle. Poly-grain structure is visible in the right side of the particle.

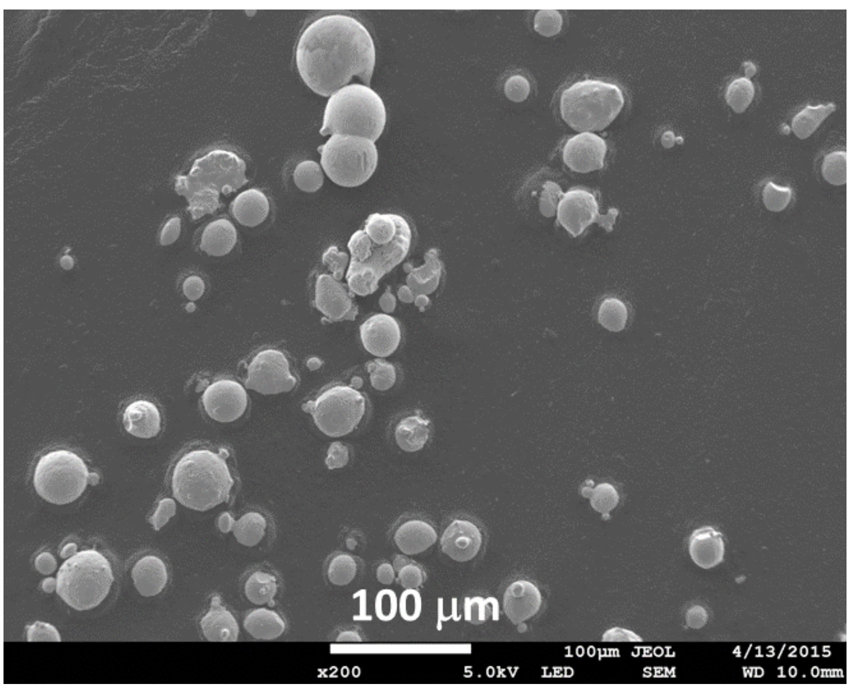

Figure 1: SEM image of the 15-5 PH1 powders

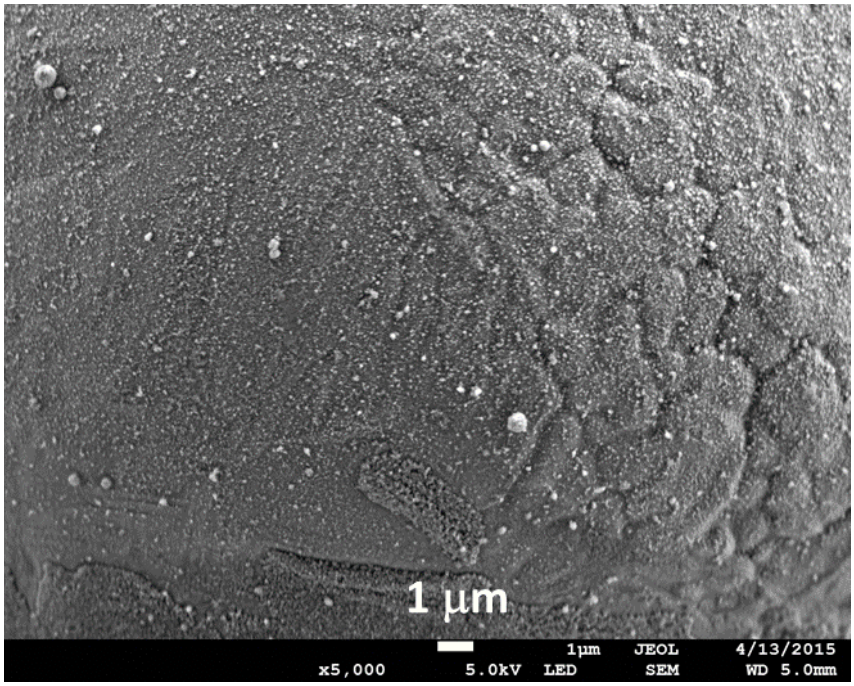

Figure 2: SEM image showing surface texture of the powder

Compositional analysis was conducted by using energy-dispersive X-ray spectroscopy (EDS) at powder surfaces, as shown in Figure 3. The resulting element compositions of selected area 1 (in Figure 3) are shown in Figure 4.

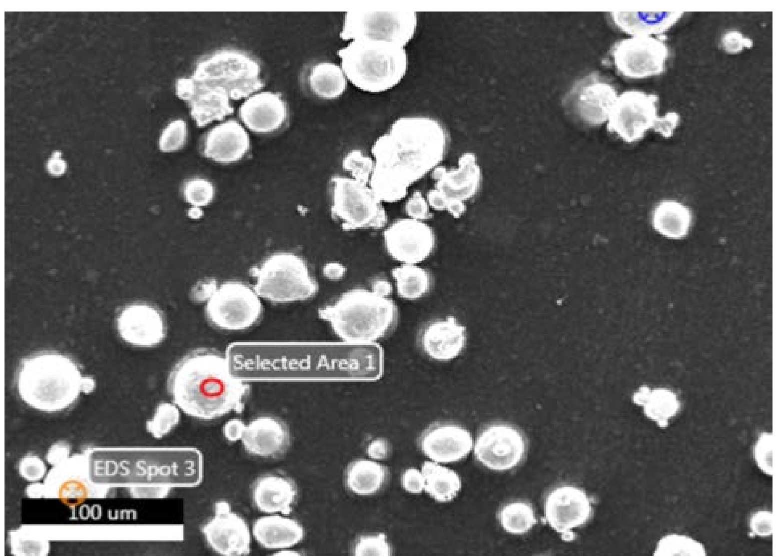

Figure 3: Locations of EDS sampling

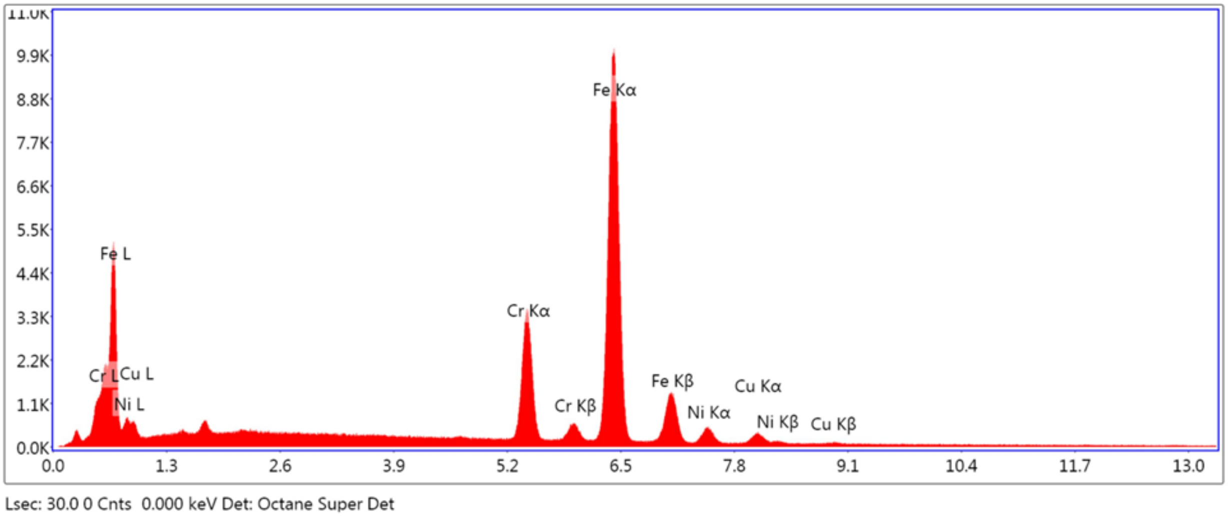

Figure 4: EDS for elements in selected area 1 (in Figure 3).

The detailed concentrations of each element are listed in Table 1. Fe, Cr, Ni and Cu are the four major elements. The compositional data are in good agreement with the EOS powder datasheet [3].

Table 1: Elemental composition of 15-5 stainless steel powder

Element	Weight %	Atomic %	Atomic % from reference [3]
CrK	13.33	14.27	14 ~15.5
FeK	78.27	78.03	balance
NiK	4.73	4.48	3.5-5.5
CuK	3.67	3.22	2.5-4.5

<u>DMLS printed 15-5 stainless steel components</u>

A DMLS printed part using the PH-1 powder was analyzed, as shown in Figure 5. Detailed regions, such as the curved surface, were imaged by using SEM.

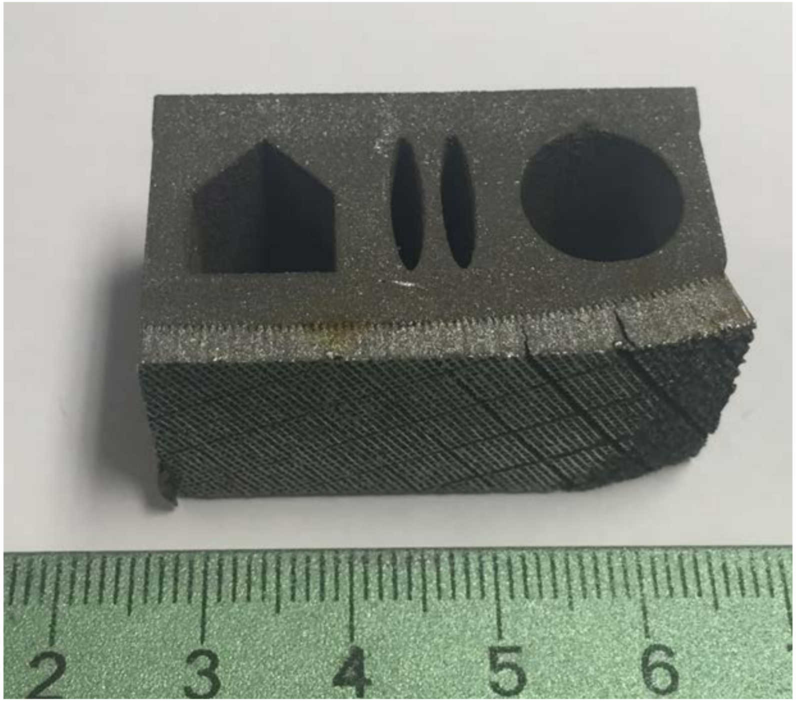

Figure 5: DMLS printed sample for microstructure analysis. Ruler unit is cm.

Figure 6 shows the SEM image shows the edge of the elliptical-shaped hole in Figure 5. Rough surface can be observed around the printed part since the residual metal powders adhered on the surface. More powders can be found on the curved surface than the flat surface.

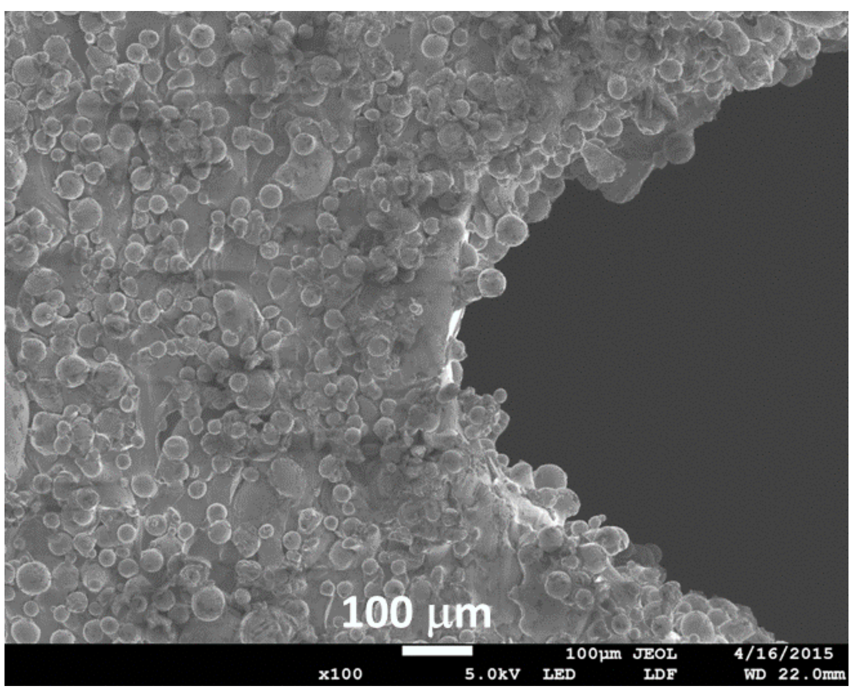

Figure 6: SEM image of DMLS printed part

The surface roughness of another 15-5 stainless steel printed part was studied by atomic force microscopy, as shown in Figure 7. The three-dimensional surface roughness map is shown in Figure 8. The maximum surface roughness in the measured are ($20\times20\ \mu m^2$) of this sample is about 0.93 μm.

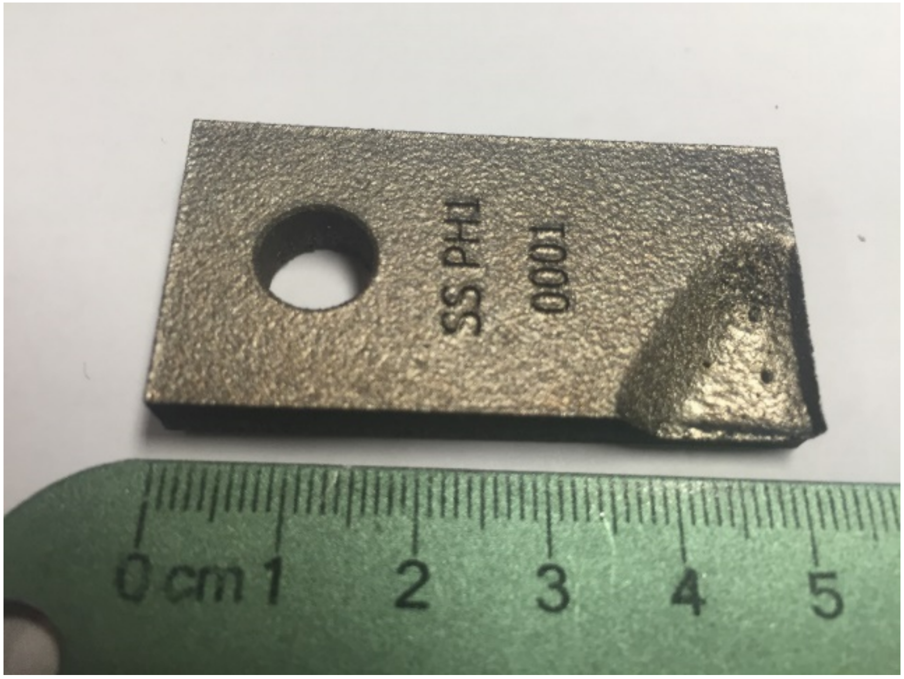

Figure 7: DMLS printed part for AFM analysis

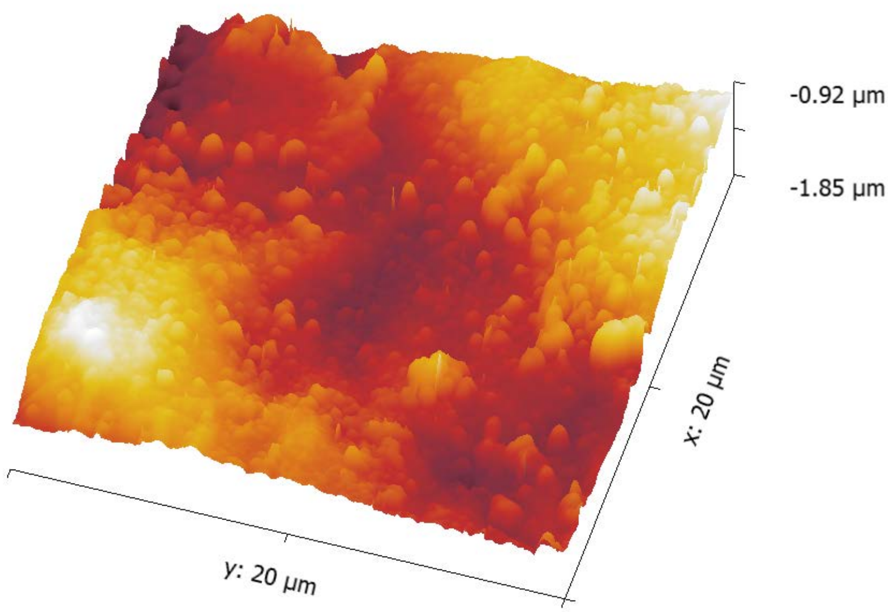

Figure 8: AFM measured surface roughness of 15-5 stainless steel printed part

The measured Rockwell microhardness according to ASTM 18E-15 is HRC 42.9±0.3 (load 150 kgf). The result is in good agreement with EOS datasheet [3], which is ~40, after age hardening. The indentation mark of the HRC is given in Figure 9.

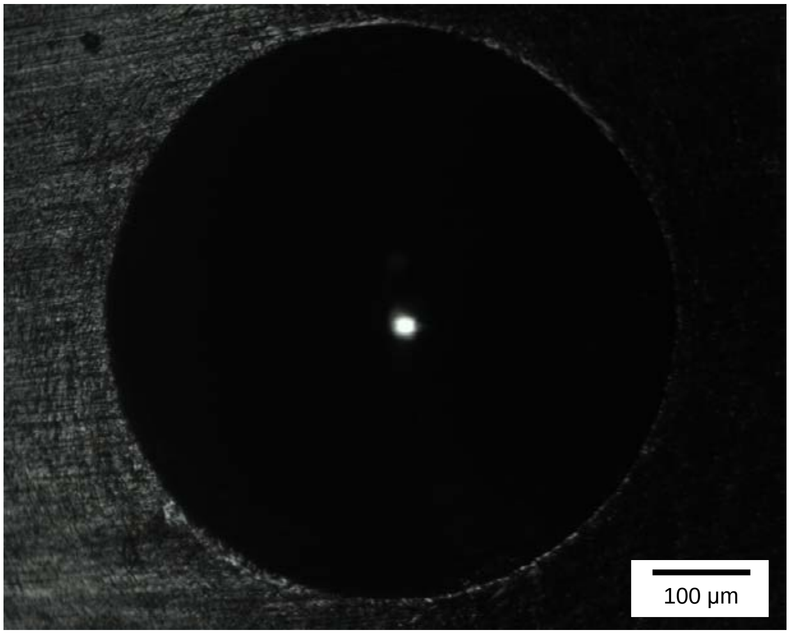

Figure 9: HRC indentation mark

Summary

15-5 PH1 stainless steel metal powders and printed parts have been characterized. Most powder particle are in spherical with a particle size of 5 ~ 60 μm. Chemical compositions of the powder were also measured by EDS and compared well with the literature data. Surface roughness was measured by AFM, the thickness of rough surface is about 1 μm. The measured Rockwell hardness is HRC 42.9±0.3, which is also in good agreement with literature.

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