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Laser polishing of additive manufactured CoCr alloy components with complex surface geometry

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ABSTRACT

Laser polishing, capable of polishing selective nonplanar areas, is exploited to improve the surface roughness of additive manufactured metal components. It offers a highly repeatable, higher speed polishing process as well as low labor costs compared with traditional mechanical abrasive polishing. In spite of the fact that many studies can be found on laser polishing processes, few have reported that focus on metal components, manufactured additively by selective laser melting (SLM) technology, with geometrically different complex surfaces. This paper presents a novel method to reduce the surface roughness of Cobalt Chromium (CoCr) components with complex surface geometry by using a layered polishing method which can constantly adjust the defocusing distance of the laser along with the surface shape of the components. The optimized laser polishing parameters used were firstly obtained from the test results on planar surfaces of CoCr alloy samples and samples with complex surface geometry were then polished based on the laser parameters. Characterizations for the laser polished samples were conducted using optical profiling and scanning electron microscopy, showing that the surface roughness was reduced significantly in comparison with the as-received samples. A reduction of up to 93% in surface roughness was achieved. The mechanical hardness was also characterized by testing for Vickers hardness, which indicated the surface hardness of the laser polished samples was enhanced by 8%. Moreover, a simple and effective model was developed to illustrate the method of laser polishing on the complex surface geometry of additive manufactured CoCr alloy components. The analytical model is helpful in understanding and evaluating the underlying mechanisms of laser polishing.

1. Introduction

In recent years, selective laser melting (SLM), which is a category of additive manufacturing technology, has been exploited to manufacture metallic components with complex surface geometries (Bremen et al., 2012). The approach in SLM is to melt minute metallic powder and build net-shape components layer by layer. The actual applications for SLM components usually have high requirements on the surface roughness. For example, SLM components for medical implants would require a very smooth surface to prevent bacterial growth and tissue damage (Gora et al., 2016). However, the surface quality of SLM components is generally lower than that for the other alternative manufacturing processes. As described (Strano et al., 2013), the surface roughness is usually affected by the 'Stair Step' effect and the 'Balling' effect. The 'Stair Step' effect refers to the stepped approximation by the layers of curved and inclined surfaces. During the melting process, many tiny metallic powder particles would adhere to the surface of SLM components, unwantedly, resulting in the 'Balling' effect.

Compared with the traditional polishing methods, such as mechanical abrasive or electrochemical, laser polishing has shown good potential for selectively polishing metals and alloys fabricated by SLM. Moreover, as laser polishing is also a type of non-contact polishing technique which does not involve load transmission between the polished components and equipment, it could overcome some of the drawbacks and difficulties of traditional surface treatment processes that affect the structural deformation.

Previous research has shown that the laser polishing process not only enhances the surface roughness of metallic components, but also improves the surface properties. For example, Mai and Lim (2004) reduced the roughness of 304 stainless steel from 195 nm to 75 nm, increased the surface reflectance to 14% and decreased the diffusive reflectance to 70% using laser polishing technology. Lamikiz et al. (2007) showed that a laser polished surface presented slightly higher and more homogeneous hardness, and almost had no heat affected zones or cracks. It is evident that laser polishing could effectively improve the surface properties of SLM parts. For example, Schreck and Zum Gahr

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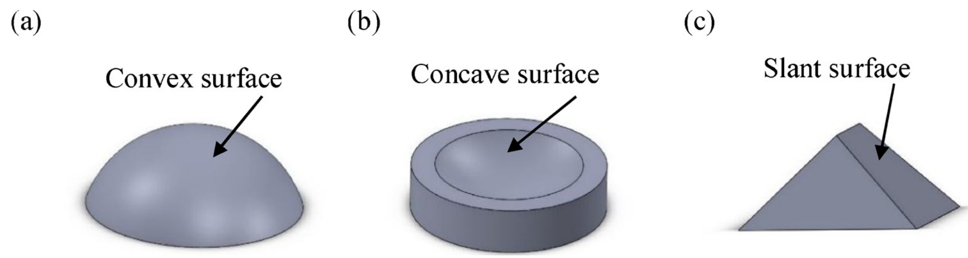

Fig. 1. Different types of samples with complex surface geometry. (a) Convex surface, (b) concave surface and (c) slant surface.

Table 1
Basic laser polishing parameters, including power, scanning speed and hatching space.

Factors	Level 1	Level 2	Level 3	Level 4
Power (W)	30	40	55	70
Scanning speed (mm/s)	15	50	100	300
Hatching space (mm)	0.02	0.03	0.04	0.05

Table 2
Polishing strategies and corresponding energy densities.

Strategy	Power (W)	Scanning velocity (mm/s)	Hatching space (mm)	Energy density (J/mm^2)
1	30	300	0.04	3
2	30	100	0.05	6
3	30	50	0.02	30
4	30	15	0.03	67
5	40	300	0.05	3
6	40	100	0.04	10
7	40	50	0.03	27
8	40	15	0.02	133
9	55	300	0.02	9
10	55	100	0.03	18
11	55	50	0.04	28
12	55	15	0.05	73
13	70	300	0.03	8
14	70	100	0.02	35
15	70	50	0.05	28
16	70	15	0.04	117

Table 3
Experimental parameters designed by using the orthogonal testing methodology and the results of the surface roughness.

No.	Power (W)	Scanning speed (mm/s)	Hatching space (mm)	Surface roughness Sa (μm)	Sa reduction (%)
1	30	300	0.04	4.55	−7.6
2	30	100	0.05	4.93	−16.5
3	30	50	0.02	6.87	−62.4
4	30	15	0.03	9.43	−122.8
5	40	300	0.05	2.11	50.1
6	40	100	0.04	1.61	62.1
7	40	50	0.03	4.55	−7.5
8	40	15	0.02	12.71	−200.3
9	55	300	0.02	0.92	78.2
10	55	100	0.03	1.12	73.6
11	55	50	0.04	1.59	62.5
12	55	15	0.05	1.91	54.8
13	70	300	0.03	0.73	82.8
14	70	100	0.02	1.35	68.2
15	70	50	0.05	1.59	62.4
16	70	15	0.04	2.59	38.9
K1	25.78	8.32	10.54		
K2	20.98	9.00	10.33		
K3	5.54	14.60	15.82		
K4	6.25	26.63	21.85		
k1	6.45	2.08	2.64		
k2	5.24	2.25	2.58		
k3	1.39	3.65	3.96		
k4	1.56	6.66	5.46		
R	5.06	4.58	2.88		

(2005) found that laser polishing could be beneficial for optimizing the structure of a component by improving particular tribological properties. Therefore, laser polishing process on SLM parts deserves special consideration in melting a certain thickness of the surface and redistributing the material, so that a smoother topography than the previous surface condition could be produced (Ramos-Grez and Bourell, 2004).

At present, studies have been conducted on CoCr alloy samples with a planar surface, which verified that laser polishing can be an effective way to smooth the as-received surface of CoCr alloy samples fabricated by SLM. Different polishing strategies were tested to optimize the parameters, and as a result, the surface roughness could be reduced significantly by using identical parameters. However, reports on laser polishing on complex geometric components made of CoCr alloys are rare, as well as their properties after smoothing by laser polishing. The morphology of a nonplanar surface is more complex, leading to great difficulty in controlling the defocusing distance, so the polishing process is more complicated compared with that of a planar surface. Moreover, a stable defocusing distance is indeed important during the laser polishing for a nonplanar surface, which is rarely mentioned in the literature.

This paper focuses on a study of CoCr alloy samples with complex surface geometry, fabricated by SLM and processed by using a layered laser polishing method. Differing from the polishing process on planar samples, the interaction between the laser and surface geometry is more complicated, and requires optimized parameters to obtain satisfactory results. Orthogonal testing methodology was applied to design the parameters for the primary experiments on planar samples. Further experiments were based on the optimized parameters and the properties of the polished complex surface geometry were analyzed in detail. A layered laser polishing method was developed, and a geometric model was built to help evaluate the process. Based on the geometric model, the working distance could remain constant when conducting the experiments by using a 2D fiber laser, which is important in achieving a final smooth surface morphology. Characteristic observations of the complex surface geometry were conducted using optical profiling, scanning electron microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDX), metallographic microscopy, and a Vickers hardness tester to analyze and quantify the surface properties of the samples before and after laser polishing.

2. Experimental procedure

CoCr alloy samples with planar surface and complex surface geometry (convex surface, concave surface, slant surface as shown in Fig. 1) fabricated independently by means of selective laser melting were used in the experiments. Each sample was clearly labelled to distinguish the particular type of surface geometry to be studied. The CoCr powders used were supplied by SLM SOLUTIONS company with a density of 4.36 g/cm^3 (composition: Cr = 28.23%, Co = 64.76%, Mo = 5.84%, Si = 0.46%, N = 0.06%, Mn = 0.50%, Fe = 0.04%,