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On the machining of selective laser melting CoCrFeMnNi high-entropy alloy

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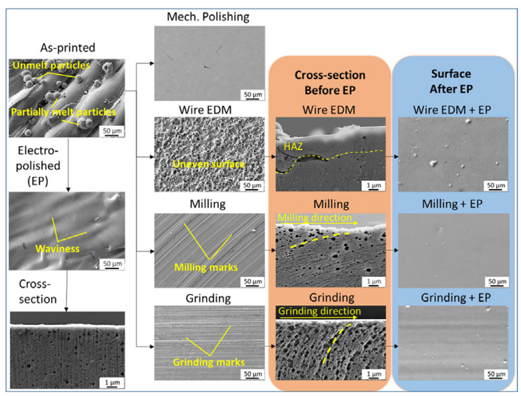
HIGHLIGHTS

- Studied the machinability of selective laser melt CoCrFeMnNi high-entropy alloy.
- Evaluated the effects of different machining processes on surface and subsurface quality were quantitatively.
- Identified the correlation between microhardness, residual stress and subsurface deformation.

GRAPHICAL ABSTRACT



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ABSTRACT

High-entropy alloys (HEAs) have attracted significant attention due to its superior low temperature mechanical properties. Recently, with the success of 3D additive manufacturing (AM) of CoCrFeMnNi HEA by selective laser melting (SLM), the fabrication of complex components in one step became possible. However, due to the low surface quality, post-machining is necessary. Up to date, there is no study that comprehensively reported the machinability of SLM CoCrFeMnNi HEA. Hence, this research presents a pioneer work on the machinability study of SLM CoCrFeMnNi HEA by commonly used mechanical, thermal and electro chemical machining processes. The surface and subsurface quality generated by different machining processes were quantitatively evaluated from the aspects of surface morphology and roughness, microhardness, residual stress and subsurface quality. The results show that milling and grinding smoothed the surface, enhanced surface microhardness but induced tool marks and compressed residual stresses. Wire EDM flattened the surface but caused a heat melt layer resulting in the increase of the tensile residual stress and surface microhardness. EP released the residual stress and with the combination of mechanical and electrical processes, smoother surfaces were obtained and subsurface damages were removed. A super smooth surface without subsurface damages was achieved by mechanical polishing.

1. Introduction

High entropy alloys (HEAs) have drawn intensive attention since its inception due to their novel alloy design concept and outstanding

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mechanical properties [1–3]. From the alloy design perspective, the HEA contains at least five elements and usually form a single phase. The mixing entropy is proposed to stabilize the single phase formation, though its role is still in debate [4]. A number of novel HEAs have been developed with the research efforts [5]. As the firstly reported HEA, the CoCrFeNiMn stands out and has drawn broad investigation including the phase formation, phase stability and mechanical properties [6,7]. It was reported that this HEA has a very stable single face-centered-cubic (FCC) phase and exhibits very high fracture toughness at the cryogenic temperature [8]. With its outstanding low temperature mechanical properties, the CoCrFeNiMn HEA shows potential applications in some specific conditions requiring low temperature.

The additive manufacturing (AM) technologies are becoming increasingly prominent in the materials science region [9,10] and has broad applications in industry for fabricating parts with complex geometry in a layer-by-layer method. Up to now, several engineering materials could be fabricated, such as Al alloys [11], Ti alloys [12], stainless steel [13] and Polyamide 12 [14]. Compared with the conventional manufacturing technologies, the AM could produce the 3D components directly based on a layer by layer manufacturing method, and could fabricate samples with complex geometries [15]. Among the various AM technologies, selective laser melting (SLM) is one of the preferred technologies, which involves the layer by layer melting of the powder using a laser beam until the designed geometry is achieved [16]. Besides, SLM could fabricate samples with outstanding mechanical properties due to the fast cooling process [17,18].

However, the investigation of SLM of HEAs is still very rare [19] though several works have reported the printability of HEAs with electron beam melting (EBM) [20,21]. As for CoCrFeNiMn HEAs, its printability with SLM has recently been reported [22]. The results indicate that near fully dense samples could be fabricated with superior tensile properties. However, due to the nature of the powder-based layer by layer deposition process, the surface quality and dimensional accuracy of CoCrFeMnNi HEAs fabricated by SLM process cannot fulfil the requirement of industrial application. Therefore, subsequent machining processes become necessary to improve the surface quality of the as-printed CoCrFeMnNi HEAs. The investigation on machining of HEAs, which is inevitable for practical applications, is not commonly reported. To date, several works have investigated the processing of HEAs with welding technologies, such as the electron beam welding [23] and friction stir welding [24]. In terms of machining, although Polishetty et al. did some preliminary work on machinability assessment of multi component HEAs [25], it is noticed that no research has comprehensively reported the machinability of SLM CoCrFeMnNi HEA. Thus, it is urgent to investigate this issue to pave the way for their applications.

Hence, this research presents a pioneer work to investigate the machinability of SLM CoCrFeMnNi HEA and to evaluate the effects of different machining processes on surface and subsurface quality. The machinability was studied by commonly used mechanical, thermal and electro chemical machining processes such as milling, grinding, wire electrical discharge machining (EDM) and electropolishing (EP). Wire EDM imposes electrical discharge energy to melt the materials so as to obtain the desirable form and surface finish. Precision milling and grinding provide high dimensional accuracy and good surface finish for high quality components with complex geometries. Milling process can also be considered as cutting process with the multi-cutting edges. Mechanical polishing using loose abrasives aims to achieve super smooth surface with no subsurface defects. EP adopts electrical power to dissolve the material and desires to smooth the surface and remove the deformed layers.

Table 1
Experimental conditions of different machining processes.

Processes	Tool	Parameters
Milling	Tungsten carbide tool (10 mm in diameter)	Feed rate: 50 mm/min. Feed depth: 50 μm Material removal depth: 400 μm
Grinding	Electroplated diamond wheel (300 mm in diameter & 8 mm in width)	Feed rate: 3000 mm/min. Feed depth: 5 μm Material removal depth: 300 μm
Mechanical polishing	Colloidal silica slurry & polishing cloth	Average particle size: 50 nm Rotation speed: 100 rpm
Wire EDM	Copper wire	Wire diameter: 0.2 mm Feed rate: ~1 mm/min.
EP	20 vol% of sulphuric acid in methyl alcohol	Material removal depth: 50 μm Applied voltage: 12.5 V

The paper begins with the introduction of sample preparation and experimental conditions, followed by surface and subsurface quality evaluation from the aspects of surface morphology, surface roughness, microhardness, residual stress, and subsurface quality. Finally, some conclusions regarding the machinability of SLM HEAs are obtained with the interrelations between surface quality and process parameters.

2. Experimental

2.1. Sample preparation

The prototype CoCrFeNiMn HEA has been shown to exhibit sound printability through SLM. In this study, the volumetric energy density is about 60 J/mm^3 and the sample with relative density of 99.2% could be obtained. The as-printed materials show good mechanical properties compared to the cast counterparts [24]. The near spherical CoCrFeMnNi HEA powders have an average particle size of 36 μm. A SLM system, Prox300 (3D systems) with a 500 W Ytterbium laser, was used to fabricate the specimens. The processing parameters are as follows: the laser power of 240 W, the layer thickness of 40 μm, and the scanning speed of 2000 mm/s. Block specimens for testing were fabricated with a dimension of 30 × 10 × 5 mm^3. The as-printed CoCrFeMnNi HEA sample is

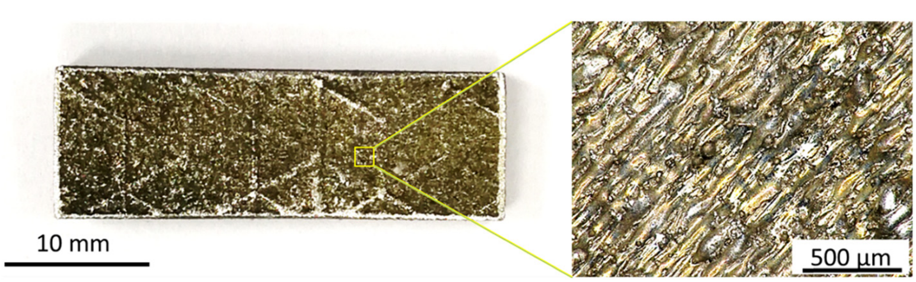

Fig. 1. As-printed CoCrFeMnNi HEA sample.