Materials and Design 155 (2018) 384–395

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Deposition behavior, microstructure and mechanical properties of an in-situ micro-forging assisted cold spray enabled additively manufactured Inconel 718 alloy

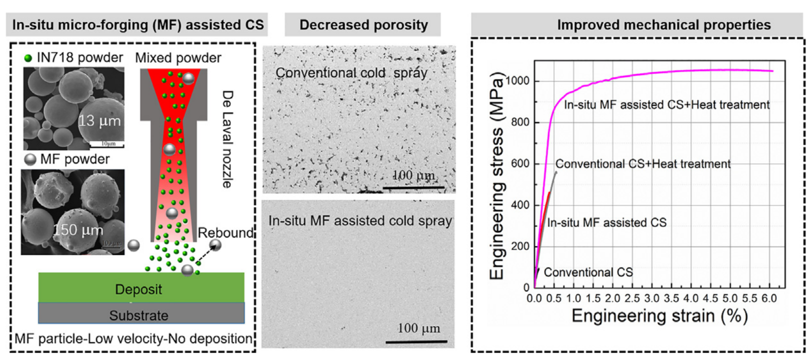
Xiao-Tao Luo [a,*], Meng-Lin Yao [a], Ninshu Ma [b], Makoto Takahashi [b], Chang-Jiu Li [a,*]

[a] State Key Laboratory for Mechanical Behavior of Materials, School of Materials Science and Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China
[b] Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan

HIGHLIGHTS

- In-situ micro-forging was introduced to cold spray by a facile approach.
- Fully dense IN718 deposit was achieved without any contamination.
- Increased deposition efficiency induced by oxide scale removal was first detected.
- Ultimate strength increases from 96 to 464 MPa due to the micro-forging effect.
- Effect of heat treatment on microstructure and tensile behavior was studied.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 April 2018
Received in revised form 21 May 2018
Accepted 15 June 2018
Available online 18 June 2018

Keywords:
IN718 alloy
Additive manufacturing
Cold spray
In-situ micro-forging
Porosity
Mechanical properties

ABSTRACT

Cold spray is capable to additively manufacture oxide-free metallic parts in open air due to its low processing temperature. However, for metals with relatively high hardness such as Inconel 718 superalloy (IN718), it is still a big challenge to get dense deposits by using low-priced nitrogen gas. In this work, In-situ micro-forging (MF) was introduced to cold spray by mechanically mixing big-sized 410 stainless steel (410SS) particles into the IN718 powder so that the deposited IN718 layer can be hammered and plastically deformed by the MF particles during spraying and results in fully dense deposits. As 50 vol% MF particles were mixed into the IN718 powder, the porosity was decreased from 5.6% to 0.26%. Due to the low impact velocity, 410SS particles were not embedded into the IN718 deposits and the possible contamination was avoided. An oxide scale removal induced increment in deposition efficiency was detected for the first time. Due to the lower porosity and enhanced inter-particle bonding, a great improvement in ultimate strength from 96 to 464 MPa was achieved by the in-situ MF effect. After heat treated at 1200 °C for 6 h, the sample fractured at a high strength of 1089 MPa and revealed a ductile fracture manner.

© 2018 Published by Elsevier Ltd.

1. Introduction

Additive manufacturing of metallic components has been rapidly evolving since it can be used to fabricate end-use products in aircraft, dental restorations, medical implants, automobiles, and even fashion

* Corresponding authors.
E-mail addresses: xiaotaoluo@mail.xjtu.edu.cn, (X.-T. Luo), licj@mail.xjtu.edu.cn (C.-J. Li).

https://doi.org/10.1016/j.matdes.2018.06.024
0264-1275/© 2018 Published by Elsevier Ltd.

products. There are two categories of additive manufacturing processes available for metals, namely the powder bed fusion and the directed energy deposition which are being developed well in recent years. In these two processes, high energy beam techniques utilize laser, electron beam, plasma arc, gas metal arc etc., as the heat sources to melt/sinter the metals layer by layer [1–3]. Apart from these high-energy-beam based techniques, cold spray has also been of great interest in recent years for additive manufacturing due to its low processing temperature [4–6]. It is worth noting that although the cold sprayed metals show poor ductility at the as-deposited state, post-spray heat treatment has been demonstrated to be an effective approach to recover the intrinsic ductility of the deposited materials [4–6]. In cold spray, micro-sized particles (5–70 μm) are accelerated to supersonic velocities in a De-Laval nozzle by compressed N_2, air or He at relatively low processing temperature (<1000 °C and material dependent) and impact onto the substrate. The deposit is formed by accumulated bonding of the particles assisted by high velocity impact induced plastic deformation at completely solid state. Owing to the low processing temperature and high material deposition rate (up to 10 kg/h), cold spray has following advantages vis-a-vis high energy beam based additive manufacturing techniques. I) Metallic materials free of oxidation can be deposited in open air [7–9] so that it is capable to additively manufacture workpieces having large sizes. At the same time, the complex thermal history involving directional heat extraction, repeated melting and rapid solidification in high energy beam based additive manufacturing processes can be avoided [1–3, 7–9]. II) Temperature sensitive materials such as nanocrystalline metals [10], metallic matrix nanocomposites [11], Al and Mg based alloys with low melting temperatures [12, 13] etc. can be built up. III) Composite materials and composite structures can be prepared simply by using mixed powders and changing the feedstock powder materials, respectively, without considering the thermal expansion coefficient mismatch and chemical reactivity among different components [11]. IV) Compressive residual stress is commonly realized in the cold sprayed deposits hence, the tensile residual stress induced cracking or failure associated with deposits made on workpieces using high energy beam additive manufacturing can be avoided [14, 15]. It has been demonstrated that mechanical properties such as hardness, strength, elastic modulus and toughness of the cold spray deposits depend entirely on their microstructure, especially the porosity. Gärtner et al. [16] reported that when the porosity is decreased, a significant improvement in tensile strength of the Cu deposit could be achieved. So far there are mainly two strategies to enhance the plastic deformation, inter-particle bonding and decrease the porosity of the cold sprayed deposits, they are: I) increasing the particle velocity to enhance the driving force for the plastic deformation [7] and II) heating the particles to higher temperatures to decrease the resistance to plastic deformation by thermal softening effect [17]. For relatively soft materials such as Cu, Ni, Ta and stainless steel etc., dense deposits can be achieved by spraying at high gas pressure (up to 5 MPa) and relatively high gas temperature (up to 1000 °C) by using nitrogen as the processing gas [18]. Yin et al. [17] found that the deposition efficiency of Cu powder was greatly improved, and the porosity of the resultant deposit was remarkably decreased by preheating the feedstock particles. However, metals with relatively high hardness such as Inconel alloys and MCrAlY based alloys (M=Ni or Co), require helium as processing gas and it should also be heated to a high temperature (>800 °C) to get dense deposits [19, 20]. The expensive helium gas makes cold sprayed hard metals very difficult to be industrialized. Low cost cold spray approaches capable of depositing high quality hard metallic deposits are desired. In cold spray, the previously deposited layer is inevitably impacted and forged by the following particles. In our previous study involving cold spraying of Ti coating, it was found that such forging effect can in-situ densify the previously deposited layer [21]. However, the in-situ forging effect induced by the sprayed particles alone is very limited due to their low kinetic energy. In our previous study [22], large-sized peening powder was blended into depositing material powders to introduce an extra forging to the deposits and the in-situ densification effect was firstly verified in Ti and Ti6Al4V. However, it was found that deposition/embedment of peening particles was observed in Ti deposit and the effect of the enhanced forging on inter-particle bonding quality and mechanical properties was not studied yet. In this work, Inconel 718 (IN718), one of the most widely used superalloy, was selected as a candidate feed-stock material. Enhanced in-situ micro-forging effect is introduced by mechanically mixing portly sized 410 stainless steel particles (>150 μm) into the spraying particles. This attempt was made with an aim that the deposited IN718 particles would be hammered and plastically deformed by the large-sized 410SS particles with much higher kinetic energy than sprayed particles during deposition resulting in a dense deposit. The dependency of deposition behavior of IN718 powder, microstructure and mechanical properties of the deposits on MF particle content were systematically investigated. Effect of the high temperature post-spray heat treatment on the microstructure and mechanical properties was also studied. The methodology adopted in this article can potentially be considered as a low-cost approach to get dense metallic deposit with cold spray having N_2 as working gas.

2. Experimental procedure

2.1. Materials

Commercial gas atomized IN718 powder (Praxair Surface Technologies) was used as the spray powder. As shown in Fig. 1a and b, the IN718 particles exhibit a spherical morphology with dense microstructure. The particle sizes of the IN718 powders were measured to be from 5 to 33 μm with an average size of 13.5 μm (Fig. 1c). It should be noted that a dendritic type microstructure can be clearly observed from the etched cross section of the as-received IN718 particles shown in Fig. 1b. Since the SEM images was taken under the back scattered electron mode, it is put forth that the brighter contrast suggests a high-volume content of heavy element/elements. Energy dispersive spectrometer (EDS) was carried out to identify the detailed chemical composition differences between the bright dendritic regions and the dark regions. The EDS results listed in Fig. 1d suggests that the bright inter-dendritic regions contain slightly higher Nb as compared to the darker areas. As displayed in Fig. 1e, f and g, 410 Martensitic stainless steel (410SS) powder with a spherical morphology and an average size of ~150 μm was blended into the IN718 powder to introduce the in-situ micro-forging (MF) effect to the deposited IN718 layer during spraying. The material and the size of MF particles were optimized for IN718 deposition according our previous practice [22]. Generally, there are mainly two considerations for the MF particle selection. I) The MF particles should have relatively high hardness so as to effectively forge/deform the deposited IN718 layer and II) embedding/deposition of the MF particle itself should be avoided. In this work, the martensitic 410SS powder has a relatively high hardness of ~340 HV and is not expensive. The large size contributes to both effective MF effect and avoidance of the MF particle deposition. Firstly, the large size ensures a high kinetic energy thus results in a considerable MF effect. On the other hand, the large size makes MF particles have very low impact velocities well below the critical velocity for bonding, so that the MF particle embedment/deposition induced contamination to the IN718 deposit can be also avoided. However, too large MF particles will decrease material building-up speed and also make it very difficult to stability feed the MF particles out, so 410SS particles with an average size of 150 μm were selected as the MF particles for IN718 deposition in the present work. It is also worth noting that the martensitic 410SS is magnetic which allows to collect the rebounded MF particles for reuse. To examine the effect of the in-situ micro-forging intensity on deposition behavior of IN718 powders and microstructure of the deposits. 25 vol%, 50 vol% and 75 vol% 410SS particles were mechanically blended into IN718 depositing powders. These raw material powders were sealed in a plastic container and then blended on a drum mixer for 2 h at a rotation speed of 40 rpm. Pure

Download English Version:

https://daneshyari.com/en/article/7216900

Download Persian Version:

https://daneshyari.com/article/7216900

Daneshyari.com