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Full Length Article

Embedding anti-counterfeiting features in metallic components via multiple material additive manufacturing

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ABSTRACT

The aerospace, automotive and medical industries are suffering from significant number of counterfeited metallic products that not only have caused financial losses but also endanger lives. The rapid development of additive manufacturing technologies makes such a situation even worse. In this investigation, we successfully applied a novel hybrid powder delivery selective laser melting (SLM) approach to embed dissimilar tagging material (Cu10Sn copper alloy) safety features (e.g. QR code) into metallic components made of 316 L stainless steel. X-ray imaging was found to be a suitable method for the identification of the embedded safety features up to 15 mm in depth. X-ray fluorescence was used for the chemical composition identification of the imbedded security tagging material. A criterion for the selection of tagging material, its dimensions and imbedding depth is proposed. The multiple material SLM technology was shown to offer the potential to be integrated into metallic component production for embedding anti-counterfeiting features.

1. Introduction

Additive manufacturing (AM), adding materials layer by layer based on sliced 3D digital models to create 3D components and products [1], has the inherent flexibility and advantages of producing complex functional parts compared with conventional manufacturing approaches [2]. The rapid growth of the additive manufacturing technology in industry predicts a potential global market value of $ 21 billion per year by 2020 [3], 48.4% of which will be accounted for the high-valued added manufacturing applications in the aerospace, automotive, and medical industries [4]. Many applications in the above fields are related to functional and safety-critical parts, such as turbine blades in jet engines, and bone reinforcing medical implants. Any defects will not only damage the associated machines/devices, but also pose threads to the human lives. Unfortunately, all these 3 industries have been suffering from the illegal counterfeits. US Federal Aviation Administration (FAA) database reported more than 20 cases of aircraft crash between 2010 and 2017 due to fake components. The US National Transportation Safety Board (NTSB) reported 135 cases of unqualified aviation components found in the airplanes between 2011 and 2016. Counterfeiting in the automotive industry is even worse, because counterfeiters can take the advantage of large batch of vehicle parts, hard to be physically distinguished from the original parts [5]. The World Customs Organization in Interpol estimated the global counterfeit vehicle spare parts market value was $ 12 billion per year [6] and the U.S. automotive parts industry has lost $3 billion in sales due to counterfeit goods [7].

The rapid adoption of AM technology makes the suppression of the counterfeit prevalence more difficult. The counterfeiters can copy generic products easily and quickly as long as they have the suitable 3D printers and 3D models that could be downloaded online or acquired through reverse engineering. General Electric (GE) filed a patent on a database platform based on the block-chain technology, an append-only transaction ledger [8], against the threat from 3D printed fake components [9]. European Union Intellectual Property Office (EUIPO) is also aware of this threat caused by new technical development [10].

Some researchers developed embedded security defective design features into the 3D CAD files in the design step [11,12], or embedding special fluorescent or visible light security features into the 3D printed polymer components [13,14,15]. Gupta et al carried out an investigation on embedding tracking codes, i.e. Quick Response (QR) code having fast readability and greater storage capacity [16], in additive manufactured parts for product authentication [12,17,18], and applied a micro-CT scanner to detect the embedded QR code in polymer components comprised of black and white resins, and laser sintered single metal component made of AlSi10Mg alloy, in which the powder particle in the QR code region were not fused and was left as lose powders [17]. This, however, may cause component fatigue failure due to the voids

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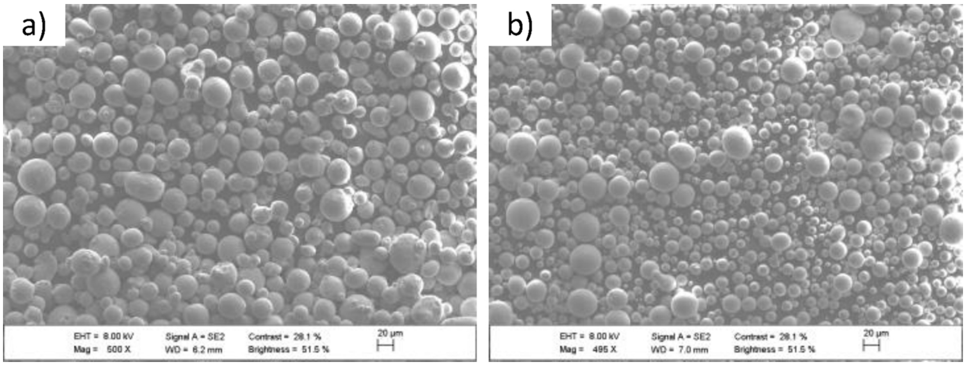

Fig. 1. SEM images of the powder materials used in this investigation a) 316 L powder, b) Cu10Sn powder.

created. The technical limitations of existing commercial metal additive manufacturing technologies, including powder-bed fusion and directed energy deposition would make embedding security features of a high resolution difficult. Firstly, present commercial powder-bed fusion machine, e.g. selective laser melting (SLM) systems can only spread a single material on the same powder layer. If such a machine is used to embed the QR codes, the pixels of the QR code have to be designed as a set of voids filled with loose powder inside the solid components or a group of blind holes on the internal surface of the hollow components. Stress concentration will distribute around these small QR pixels, i.e. voids, and they can easily lead to the 3D printed component fracture under high static/dynamic loading or fatigue failure due to cyclical stress after long working period [19,20,21]. It is notable that the density requirement of the 3D printed metal component used in the aerospace industry is close to 100%. Undesirable voids are strictly prohibited. On the other hand, multiple material metal additive manufacturing would provide an alternative solution, as dissimilar metal material having a good metallurgical bonding with the main part material can be used as a tagging material and fill the pixel voids of QR code and firmly bonded with the main building material of the component after melting. The commercial directed energy deposition systems are available for multiple material metal depositions. InfraTrac company applied such multiple material system, i.e. Laser Metal Deposition (LMD), to embed a special tag into a titanium alloy part and detected it successfully with X-ray fluorescent equipment [22]. Due to the poor processing resolution of the LMD method, e.g. at sub-millimeter scale along the horizontal direction [23], it is not suitable for printing the tiny pixels in the QR code. More seriously, due to the use of gas delivery of the powders in the LMD processes, some powder particles can splash to other parts leading to the contamination of the building material and the tagging material [24].

Therefore it is important to develop a high resolution multiple metallic material additive manufacturing technology to embed tracking codes as a new anti-counterfeiting approach. The embedded safety features should be easily and effectively identified by ordinary non-destructive testing approaches widely applied in industry, for instance, thermography, radiography, and fluorescent methods [25,26], and survive in the harsh working environment [27]. The resolution of SLM is typically 20–50 μm [28], much higher than that of directed energy deposition approaches [29]. This makes multiple material SLM a promising method to imbed tiny QR codes into the metallic components manufactured fully or partially with additive manufacturing. The University of Manchester demonstrated a novel ultrasonic selective powder delivery system integrated into powder bed SLM [30], which showed the potential for applications for the tailoring of local material prosperities in a component (e.g. medical implants), printing of mechanical-electronic integrated components (e.g. electric motors and batteries), and jewelries made of several types of precious metals. Here we applied this novel technology to a new anti-counterfeiting application that enabled security features such as a QR code to be imbedded in metallic components at the users' choice. Infrared thermal imaging, X-ray imaging, and X-ray fluorescent methods were employed to identify the tag features. Microstructural and compositional analyses of the material interface were also carried out.

2. Experimental materials and procedure

2.1. Materials

Previous investigations on multiple metallic material additive manufacturing [31,32] indicated that copper and related alloys can be metallurgically bonded well with Ti6Al4V titanium alloy and 316 L stainless steel, and the components achieved good mechanical performances, as the liquid phase contact angle between copper element and iron/titanium element was very small that led to strong thermodynamic driving force for the copper element infiltration [33,34]. Hence, copper alloys were widely applied as infiltration materials in the selective laser sintered green parts, using a copper alloy to fill the parts' internal voids strengthening the final parts [35].

The main building material involved in this investigation was spherical 316 L stainless steel powder of 10–45 μm diameters (Fig. 1a), supplied by LPW Technology Ltd., UK. Cu10Sn powder of 10–45 μm powder diameters (Makin Metal Powders Ltd. UK, Fig. 1b) was employed as the security tagging material. The thermal properties and density of Cu10Sn and 316 L are distinct [36], so they would be expected to present significant different infrared spectroscopic, X-ray fluorescent and X-ray image characteristics. As Cu and Sn elements are not present in the 316 L chemical components (Table 1), the embedded features should be more easily observed by x-ray fluorescent analysis. The base plate was made of 304 stainless steel (120 mm diameter,

Table 1
Chemical compositions of powders and the substrate used in this investigation [37].

Material	Chemical compositions (%)									
	Ni	Fe	Cr	Cu	Mo	Si	C	P	S	Sn
316 L	10.5	69.85	16.6	–	2.2	0.8	0.03	0.02	0.01	–
Cu10Sn	0	0	–	Bal.	–	–	–	0.10– 0.35	–	9.2–11.0
304	2.0	66.345–74	18– 20	–	–	1.0	0.08	0.045	0.030	–