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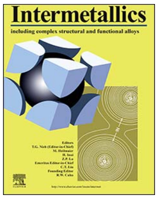

Characterisation of titanium aluminide components manufactured by laser metal deposition

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ABSTRACT

Prior work on laser additive manufacture has shown that it is only possible to produce crack free components in TiAl when using a supplementary heat source to control the cooling rate. In this work the LENS process was used to produce crack free TiAl parts without using a secondary heat source by manipulating the laser focus position.

1. Introduction

Research on titanium aluminides began in the 1950's, however, it is only over the past two decades that significant interest has occurred primarily in the aerospace and automotive sectors. In terms of weight the difference between a conventional titanium alloy such as Ti-6Al-4V (Ti6/4) is marginal, however, the ability to operate at a significantly higher temperature is attractive. From a mechanical design standpoint, the low room temperature ductility of γ-TiAl, which is typically between 0.3 and 4% depending on the alloy composition and microstructure, together with its low fracture toughness are of concern. Further details of the mechanical/physical properties and potential applications of this material can be found in reviews by Dimiduk [1], Djanarthany et al. [2] and Partridge and Winstone [3].

Laser additive deposition technologies are known by a variety of names, most of these are trade names of the various machine manufacturers or research establishments developing the processes. The process names include laser metal deposition (LMD), direct metal deposition (DMD), direct laser deposition (DLD), laser engineered net shaping (LENS), laser cladding, laser deposition welding and powder fusion welding. The processes all aim to produce fully dense metallic material parts from powder, which is melted and fused using a focused laser beam. Highly complex and accurate parts can be produced in a relatively short lead time compared with conventional manufacturing techniques. In addition to fabrication of parts, it is also possible to perform repairs and alterations using this process.

Liu and DuPont [4] studied the fabrication of TiAl reinforced with TiC on an Optomec LENS 750 machine using laser powers of between 170 and 340 W, scan speeds of 252–1000 mm/min, powder feed rates of 2.4–3.5 g/min and a layer thickness and hatch spacing of 0.254 and 0.381 mm respectively. It was found that the principle problem encountered during deposition was thermal cracking. The results showed that cracking could be reduced by varying the processing parameters to increase the incident laser energy (i.e. using higher laser power and slower scan speed) but cracking could not be eliminated. Thermal cracking was only eliminated by using an additional heating system to preheat the deposition substrate to 450 °C. Bruckner et al. [5] also studied the laser additive manufacture of crack sensitive materials (Ni based superalloys and TiAl) and could only prevent cracking by using a hybrid system with a closed loop controlled inductive heating system that used a thermal camera to keep the deposited material within a specific temperature profile. Weisheit et al. [6] studied laser surface alloying on TiAl and found that cracking could only be prevented by preheating the substrate to 400 °C, they found that reducing the power density and lowering scan speed reduced cracking but did not eliminate it. The majority of cracking formed during solidification, however some cracks occurred hours after processing due to high residual stresses. Srivastava et al. [7] found that when increasing the build height of TiAl strips produced using a blown powder laser system, the length and frequency of cracks increased which was attributed to residual stress caused by high thermal gradients.

The majority of work on laser deposition additive manufacture of TiAl has concluded that it is not possible to produce builds that do not contain cracking unless a supplementary heating system is used (e.g. heated bed, induction coil, etc) to control the cooling rate.

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Table 1
Powder composition in weight%.

C	Al	Cr	Nb	Fe	H	N	O	Ti
0.01	34.2	2.4	4.7	0.06	0.001	0.01	0.11	bal

Table 2
Particle size distribution by laser diffraction.

	D10 (μm)	D50 (μm)	D90 (μm)
Mean	54	77	105

Table 3
Processing parameters used to produce 10 mm cubes of TiAl.

Laser Power (W)	Scan Speed (mm/s)	Energy density (J/mm^2)
400	19	80.8
350	19	70.7
	15.2	88.3
250	19	50.5
	15.2	63.1
	10.2	94.6
150	10.2	56.8
	13.5	37.9

Table 4
Processing parameters used with varied laser focus position.

Scan speed (mm/s)	15.2			
Laser power (W)	300		200	
Energy density (J/mm^2)	37.96		25.3	
Focus position above plane (mm)	Below −3.81	Above +3.81	Below −3.81	Above +3.81

2. Experimental work

The material used in this investigation was gas-atomized, TiAl powder, the chemical composition of the powder is listed in Table 1. Particle size analysis using laser diffraction was conducted using a Malvern Mastersizer 3000 with air dispersion, the results are shown in Table 2. The particle size falls in the range 45–106 μm as specified.

Plates of TiAl sectioned into 5 mm in thickness, were used as the substrate material. The substrate was ground to a finish of 0.8 μm Ra then degreased using IPA before deposition.

An Optomec LENS MR7 machine was used to deposit cubes of 10 mm square by 10 mm tall. The LENS machine consists of a 500 W Nd:YAG laser, a four-nozzle coaxial powder feed system, a controlled-environment glove box and a motion control system. The powder nozzles are designed to direct the powder streams to converge at the melt pool near the focal point of the laser beam. Powder is fed to the head in a pressurised argon stream and the nozzle assembly also has an argon centre purge to protect the laser focusing lens from damage. In this process the laser and jets remain stationary while the table is moved continually providing new positions on which to deposit metal, allowing the component to build as the powder is melted and fused.

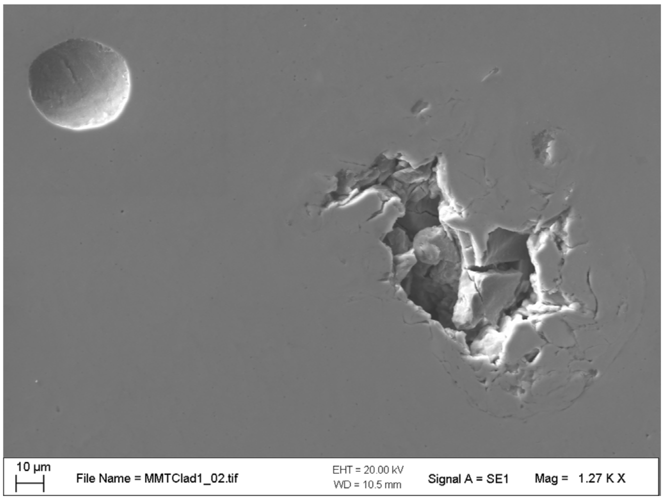
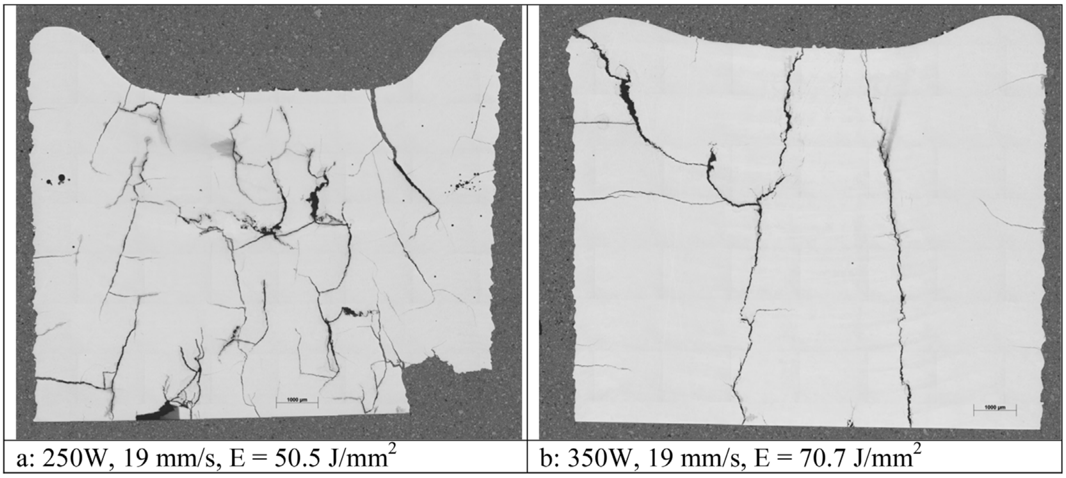


Fig. 2. Detailed SEM image of an area of lack of fusion as seen in Fig. 1a.

Different laser powers (from 150 to 400 W) and traverse speeds (from 10.2 to 19 mm/s) were used in the experiments. The powder feed rate was fixed at 2.3 g/min, see Table 3 for details. The layer thickness, hatch spacing, and stand-off distance were set at 0.254, 0.381, and 9.525 mm, respectively. The hatch path was set to meander back and forth and each layer was oriented at 90° to the previous layer. The process operates in a sealed chamber filled with an inert gas (argon), the oxygen level in the glove box was kept below 10 ppm during processing to avoid oxygen and nitrogen contamination in the deposits. The laser surface incident energy during processing (E) can be calculated with the following formula:

$$E=P/v\cdot D$$

where P is laser power, v is scan speed and D is laser beam diameter. The laser surface incident energy for each condition tested is shown in Table 3.



a: 250W, 19 mm/s, E = 50.5 J/mm^2

b: 350W, 19 mm/s, E = 70.7 J/mm^2

Fig. 1. Typical appearance of the sectioned TiAl builds.

In the LENS MR7 the laser focus is controlled by a threaded lens