

Laser Powder Welding of a $\text{Ti}_{52}\text{Al}_{46.8}\text{Cr}_1\text{Si}_{0.2}$ Titanium Aluminide Alloy at Elevated Temperature

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Abstract. A method for the joining of a $\text{Ti}_{52}\text{Al}_{46.8}\text{Cr}_1\text{Si}_{0.2}$ Titanium Aluminide alloy by laser powder welding is presented. The technique acts to join materials by consolidating powder with focused laser beam to form weld beads that fill a V joint. In order to avoid the occurrence of residual thermal stresses and hence cracking of the brittle material, the weld plates were heated to a temperature of 1173 K (= 900 °C) by an ohmic heating device, welded and then slowly cooled to produce pore and crack free welds.

Keywords. Laser welding, titanium aluminide, solidification cracking.

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1 Introduction

Extensive research into the development of γ Titanium Aluminide alloys (TiAl) has been conducted largely due to the materials' high ratio of modulus and strength to density at high temperatures, a characteristic that would engender higher fuel efficiencies in aerospace and automotive components exposed to high temperatures by replacing conventional denser materials [1]. The primary phase in γ titanium aluminide alloys, TiAl γ , possesses a FCT crystal structure comprising alternating planes of Ti and Al atoms. The phase possesses insufficient ductility and fracture toughness and hence alloy compositions tend to deviate from stoichiometry in order to retain small volume fractions of Ti rich, HCP Ti_3Al α_2 phase. This acts to improve ductility by absorbing interstitial impurities which restrict dislocation mobility within γ and by γ/α_2 interfaces acting as dislocation sinks [2]. The low ductility of titanium aluminides coupled with the high cooling rates associated with conventional welding and joining techniques leads to a high susceptibility to cracking during processing.

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It has been observed that exposure of titanium aluminide to cooling rates faster than 300 K/s will initiate cracking [3] and hence it is necessary to modify welding parameters or utilise novel processes to avoid the phenomenon. Autogenous gas tungsten arc welding has been used to successfully produce crack free welds [3] along with various solid state welding processes, notably diffusion bonding and rotational and linear friction welding [4].

In this work an alternative method of joining Titanium Aluminide is presented. The technique is known as laser powder welding and is based on the laser cladding process and is utilized at the National Laser Centre in Pretoria, South Africa for the joining of aerospace components for industrial clients [5]. Laser cladding is a laser materials deposition technique whereby beads of material are formed on the surface of an object by consolidating a stream of powder particles using a focused laser beam. By overlapping beads over the surface of a component, the process can be used to fabricate coatings with improved mechanical or corrosive properties [6]. In this work the process is used as a joining technique termed laser powder welding, where a V joint is formed by filling with beads of deposited material.

2 Experimental Method

The filler material used was gas atomized $\text{Ti}_{52}\text{Al}_{46.8}\text{Cr}_1\text{Si}_{0.2}$ powder with a particle size range of 40–70 μm . This alloy was developed at the Max-Planck-Institut für Eisenforschung GmbH for casting applications [7]. The powder is super saturated with α_2 due to the high cooling rates induced by the fabrication process. The weld plates of the dimensions 6 × 90 × 20 mm, were of the same composition in the as cast near γ state with small quantities of α_2 . Weld beads were produced using a coaxial laser cladding nozzle that is comprised of two conical forms that combine to create the walls of a cavity. The cavity is placed concentric with the beam of a 4.4 kW Rofin Sinar DY044 Nd:YAG laser and powder particles are fed into it. Powder particles entering the cavity are directed into a converging conical stream of powder (resulting from the interaction between the cavity architecture and powder particle/gas flow characteristics) which is then aligned with the focused laser spot (see Figure 1). The laser beam power used was 1 kW and the beam diameter on the work piece was 2 mm. Filler powder was fed at 0.06 g/s using a carrier gas (Helium at a flow rate of 0.13 l/s) and the

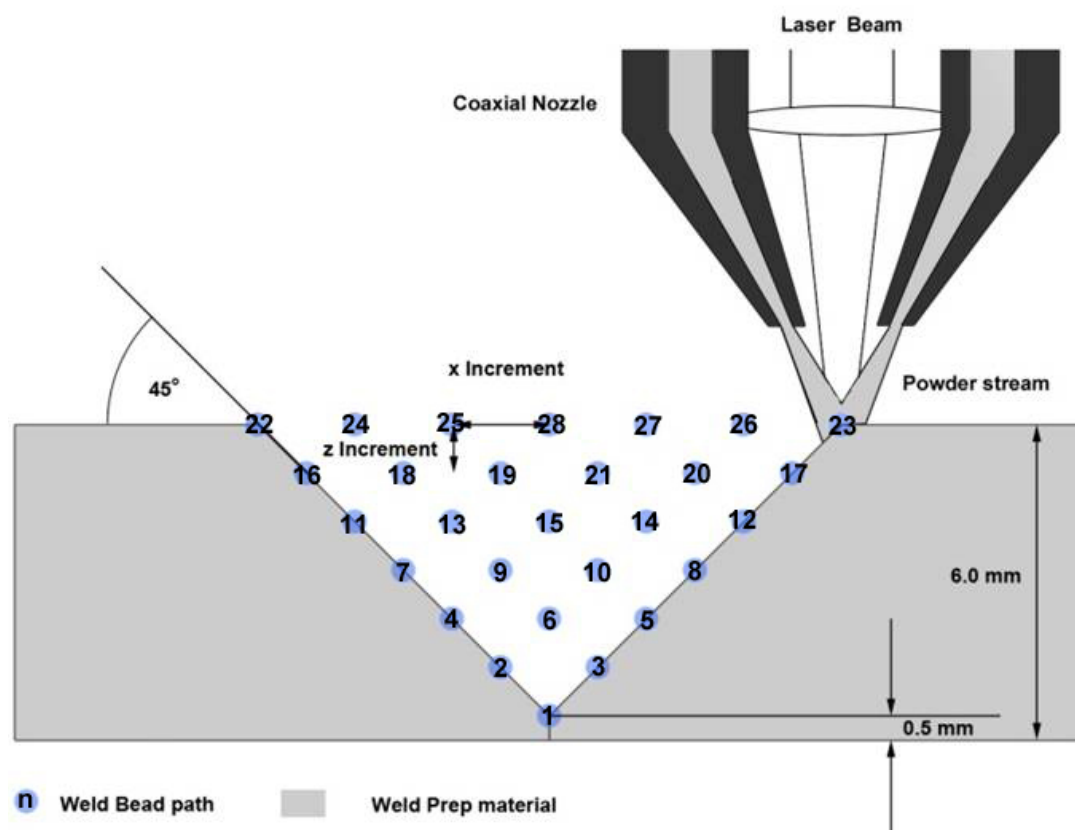


Figure 1. Schematic of deposition strategy.

nozzle was scanned at a speed of 17 mm/s using a robotic arm. A shield gas of argon flowed concentric to the laser beam to protect focusing optics and at a rate of 0.15 l/s. 45° V grooves were machined into the TiAl plate and were filled by depositing 16 overlapping beads of material that correspond to 4 layers (see Figure 1). Due to the sensitivity of TiAl to contamination from atmospheric gases the experimental setup was isolated in a chamber that was purged with argon for 12 hours prior to welding.

Previous research into laser processing of titanium aluminide has shown that the high cooling rates induced cracking in the material and that performing laser deposition at elevated temperatures alleviates the effect [8]. In this work plates of material are heated to an elevated temperature using a resistive heating device before welding is performed and then allowed to cool slowly in order to alleviate cracking. This was facilitated by coupling the sample to the outlet side of a current source. (The concept is detailed in Figure 2 (b)). Two parallel circuits were supplied by water cooled copper electrical contacts clamped to each weld plate in order to preheat both sides of the weld to exactly the same temperature before welding commenced. Energy input was modulated by PID controllers in response to temperature feedback supplied by type K thermocouples arc welded onto the sample surface which allowed for the con-

trol of plate temperature to within ± 15 K. A 500 μ m gap was left between the plates to facilitate electrical isolation.

The same device served to reduce temperature fluctuations during welding and to cool the sample down at a controlled rate after welding in order to prevent cracking. Prior to welding, the plates were heated to 1173 K ($= 900^\circ\text{C}$) at a rate of 4.5 K/s and subsequently held at the temperature for 250 s while the weld was performed. The joined plates were then cooled at a rate of 4 K/s to ambient temperature.

3 Results and Discussion

The pre-heating, clamping and laser powder welding produced satisfactory defect free welds. The welded plates were sectioned in both the transverse and longitudinal direction and metallographically prepared before the samples were etched using Kroll's reagent. Figure 3 shows a transverse section of the welded plates. Both sections showed no evidence of porosity or cracking, however a slight angular distortion of the plates' alignment is evident.

Analysis of the weld metal by means of optical microscopy revealed the presence of a columnar structure throughout the majority of material with coarser equiaxed structures at the interface between overlapping beads as

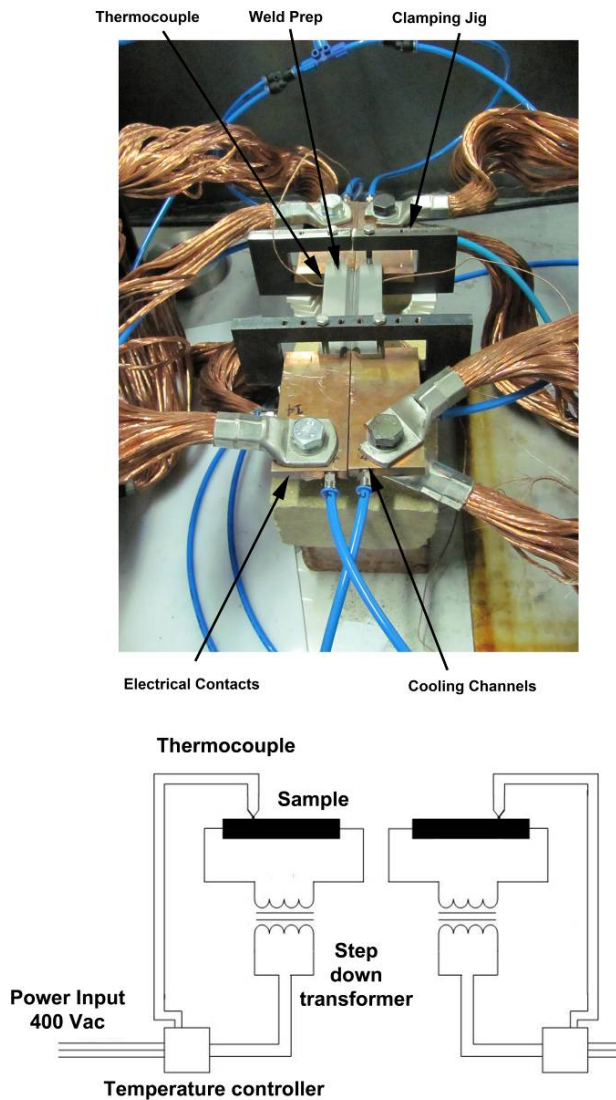


Figure 2. Weld plates in resistive heating device and (b) schematic of heater.

shown in Figure 4. Both structures are remnants of the initial solidification structure that forms as liquid TiAl transforms to the high temperature titanium β phase.

Within the solidification structures are fine lamellae indicative of α_2/γ formation (as shown in Figure 5). Figure 6 shows X-ray diffraction analysis of the weld metal which confirms the presence of a strong γ (111) peak and a much fainter (201) α_2 peak indicating the presence of small quantities of this phase. As the weld metal cools from the liquidus to the holding temperature of 1173 K (= 900 °C) the high cooling rate associated with laser processing will most likely result in transformation of $\beta \rightarrow \alpha/\gamma \rightarrow \alpha_2/\gamma$, however the low cooling rate (4 K/s) as the material is cooled through the α_2/γ field will most likely result in the formation of near γ as predicted by the TiAl binary phase diagram.

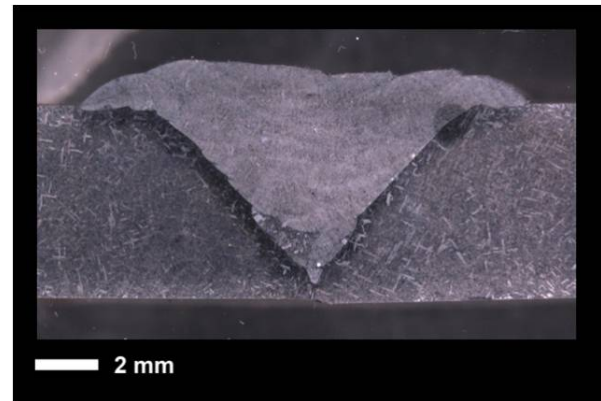


Figure 3. Transverse section of TiAl weld showing minimal distortion and no porosity.

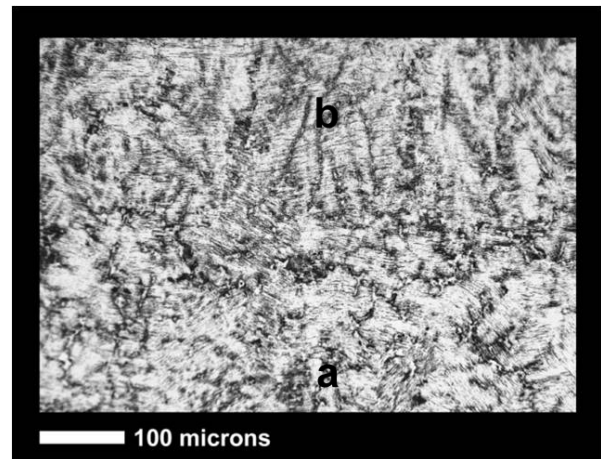


Figure 4. Optical micrograph of weld metal showing (a) equiaxed and (b) columnar solidification structures.

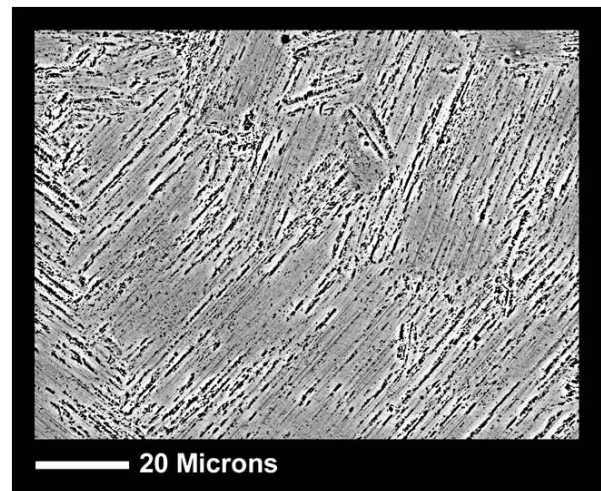


Figure 5. Electron micrograph of weld metal showing α_2/γ lamellae.

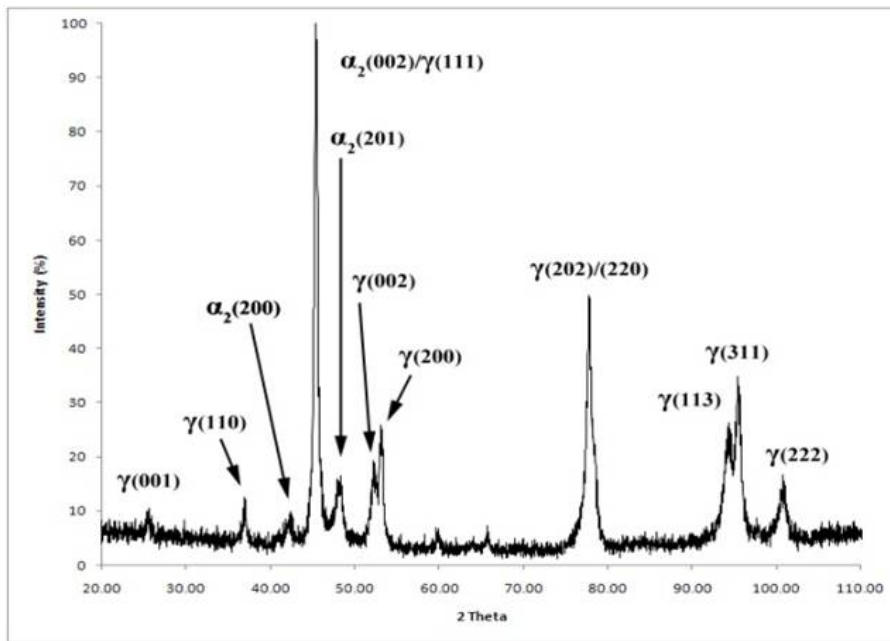


Figure 6. X-ray diffraction pattern of weld material.

Hardness testing was conducted on both longitudinal and transverse sections of the weld using a 500 g load revealing an average hardness of $HV\ 346 \pm 6$ in the base metal and an average hardness of $HV\ 325 \pm 19$ in the weld metal. There is a substantial increase in hardness to above $HV\ 400$ at the weld interface. This phenomenon could be attributed to higher cooling rates occurring as the weld beads are deposited onto base metal than onto other previously deposited weld beads. The higher cooling rates will lead to the retention of higher volume fractions of α_2 forming in these regions. Previous research into gas tungsten arc welding has shown that retained α_2 can be eliminated by post weld heat treatment [9] leading to homogenous microstructural properties.

The technique provides for a fast and effective way of welding Titanium aluminide. The method of depositing weld beads using a robotic arm allows for greater flexibility and hence welding of more complex geometries than friction based techniques and higher processing times than diffusion bonding based techniques.

Previous research has shown heating to elevated temperatures prevents the occurrence of cracking during welding of TiAl base alloys. This is conventionally performed by using a hot plate to heat the components and allowing thermal conduction to equalize temperature throughout. The use of direct ohmic heating with temperature feedback control allows for the temperature to be controlled within close limits and would allow for specific regions of a part to be maintained at a constant temperature allowing for the welding of intricate components such as turbine blisks.

4 Conclusions

- Laser powder welding at elevated temperatures provides an alternate means to join titanium aluminide, producing crack and porosity free welds.
- Direct ohmic heating provides a flexible method of heating for elevated temperature welding, allowing for a high degree of control over temperature and for the possibility of welding of complex shape.
- The weld metal display similar hardness values to the base metal with a hardened region at the weld/base metal interface.

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