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Repair of nickel-based superalloys by pulsed Nd:YAG welding with wire feeding

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Abstract

In this paper deposition of IN 625 filler wire on γ’-hardened IN 738 superalloy with pulsed laser beam welding was investigated. High-speed observation was performed to examine the influence of the spatial and temporal alignment between the pulsed laser beam and the wire feeder on the material transition from the solid wire onto the substrate. The deposition process has shown to be extremely sensitive to the wire position and orientation relative to the melt pool. To obtain stable and repeatable welding conditions influence of the significant parameters, such as the wire feed rate, the energy input, and the traverse speed should be attentively considered. Significant improvements of the process stability could be achieved with the adjustment of the wire position in the negative z-direction. The preliminary results showed the potential of this approach as an alternative automated or partially automated repairing method for worn turbine components made of nickel-based superalloys.

Keywords: Nickel-Based superalloys; Pulsed laser welding; Pulse shaping, Wire feeding, Inconel 738

1. Introduction

Polycrystalline nickel-based superalloys like INCONEL 738 LC are favored for turbine blades in land-based and aero gas turbine engines because of their excellent high-temperature strength, creep resistance, fatigue strength, hot corrosion and oxidation resistance. The outstanding high-temperature and creep strength, provided by the addition of Ti and Al to promote precipitation hardening of the ordered $Ni3(Al,Ti)$ γ’-phase within the γ-matrix, extended the use of these alloys at operating temperatures up to approximately 980 °C (Egbewande et al., 2009). During the operation turbine blades are constantly exposed to thermal, corrosive and abrasive wear environments. As a result, these components should be often replaced to avoid loss of

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engine power and its efficiency as well as possible failure. Replacing damaged components is, however, expensive due to material and machining costs. Therefore, repairing of damaged components during engine operation is rather a better option than replacing them.

In this study, repair welding of γ’ hardened IN 738 LC superalloy was carried out with pulsed laser beam welding and automatized filler wire feeding. Since the heat is supplied selectively in millisecond range and solidification of the melt pool occurs between each pulse, this technique is attractive for thin-walled components or when small residual wall thicknesses are available. Firstly, the influence of the spatial and temporal alignment between the pulsed laser beam and the wire feeder on the material transition was investigated with the aid of high speed imaging. Secondly, the impact of welding parameters was evaluated by means of geometrical characteristics of the resulting weld beads including dilution rate, contact angle and aspect ratio.

2. Results

Generally, wire feeding systems are highly sensitive to changes in processing conditions. Therefore, it is important to determine the influence of processing and laser parameters on the metal transfer between the solid wire and the melt pool, which is important for stability of the welding process. Some of the important processing parameters are wire tip position in relation to the laser beam focus, feed angle, feed direction, wire feed rate and traverse speed. Pulse peak power, pulse shape and pulse duration are among the influential laser parameters.

Initially, the spatial arrangement between the wire feeder and the laser beam was investigated. The wire tip position relative to the melt pool affects the melting behavior of the wire and the metal transfer between the solid wire and the substrate. Because of its high impact on the resulting weld shape and weld quality different wire tip positions relative to the laser beam were set. With the aid of the high speed camera, melting behavior, material transition and droplet formation were analyzed and improved. Fig 1a shows a stable welding process condition, in contrast to the unstable conditions shown in Fig 1b and c. When the wire tip position was already shifted by 100 µm out of the laser beam focus unstable process condition was observed and the material transition changed rapidly to an inhomogeneous droplet transfer mode as seen in Fig 1b.

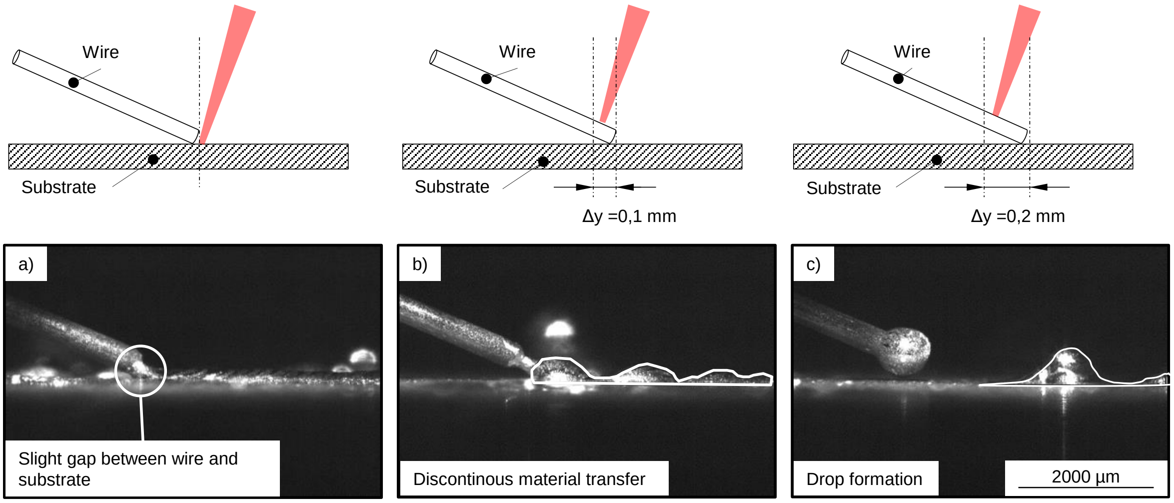

Fig. 1. Change of the material transfer from the solid wire onto the substrate due to the shift of the wire tip position in y-direction. Peak power =1,2 kW

Such alignment of the wire tip position results in highly irregular bead shapes as well as discontinuous tracks. The process limitation, where no metal transfer occurred, was reached as the wire tip was shifted 200 µm out of the laser beam.

To understand the formation of the droplet on the surface, also at slightly shifted wire tip position of approximately 100 µm, continuous images during the process were captured and analyzed. Representative images at the initial stage of the melting behavior are shown in Fig 2a. When the laser beam melts the filler material, the weld pool and the wire tip are separated as can be seen in Fig 2b. To minimize the surface energy the molten wire tip forms a spherical shape (see Fig 2c). Due to the constant feeding the wire tip is heated up by the laser irradiation, leading to the growth of the droplet until the complete wetting of the substrate is achieved. After the drop detached the substrate surface the process is repeated and a new drop will be formed directly. Moreover, once droplet transfer starts, it's difficult to stop.

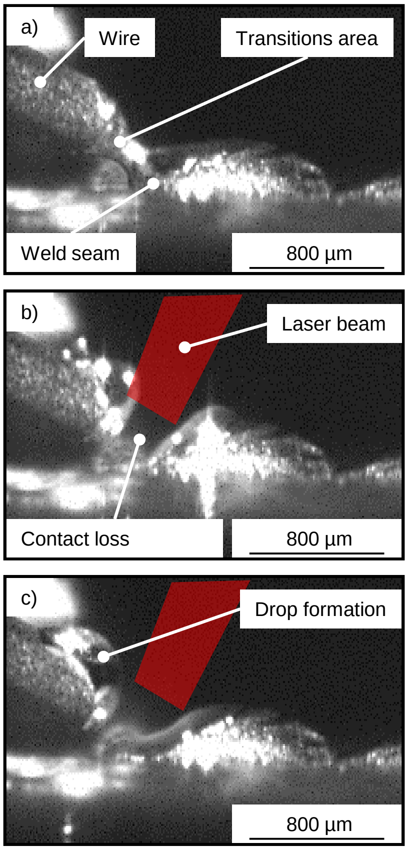

Fig. 2. Sequence of the material transition by shifting the wire tip Δy = 0,1 mm, Peak power =1,2 kW

As shown above, stable welding condition will only be achieved when smooth material transfer from the solid wire into the meld pool is present. In order to prevent drop formation as well as unstable welding process conditions even at slight deviations of the wire tip it is always necessary to keep a physical contact between the wire tip and the molten or solidified weld pool.

As shown in Fig 3, process instabilities can be compensated by the displacement of the wire tip in the negative z direction. This negative shift caused a slight deflection of the wire, whereby the required physical contact between the wire tip and the substrate can be maintained. In fact, small adjustments of 200 µm in negative z-direction significantly improved the process stability. The same positive effect may happen when the wire is fed under 30°.

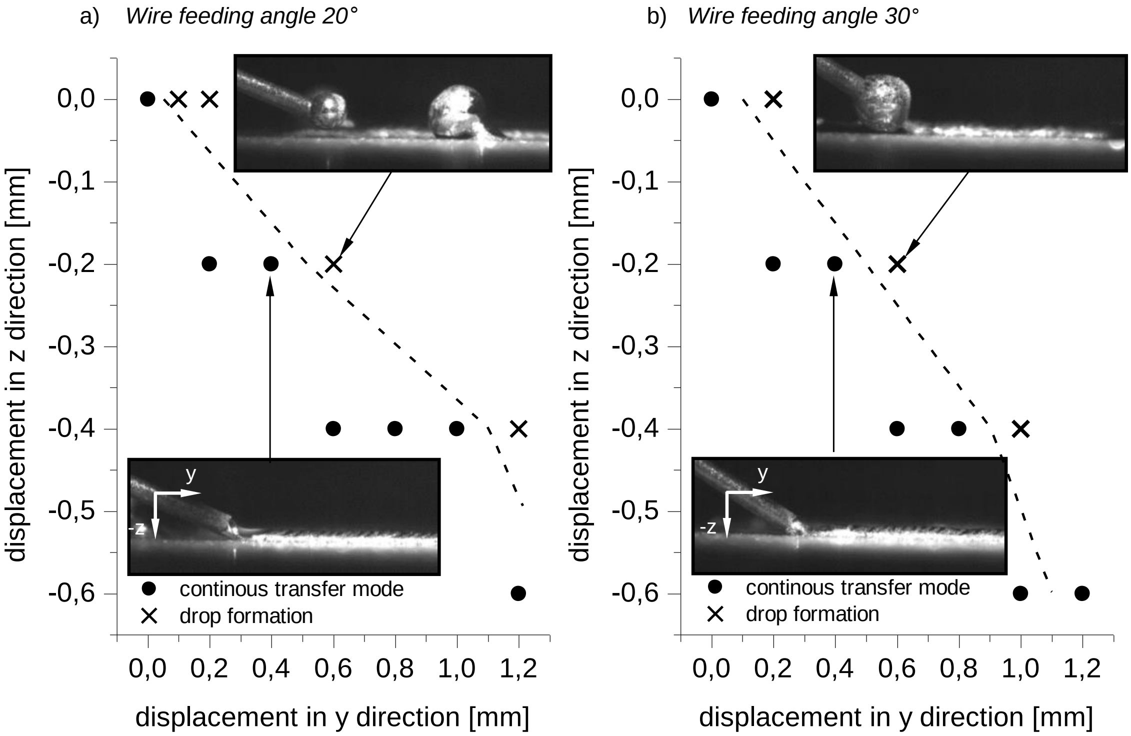

Fig. 3. Material transition in relation to the wire tip positioning z and y direction a) wire feed angle 20°, b) wire feed angle 30°, Peak power =1,2 kW

3. Conclusions

An alternative repair welding strategy for nickel-based superalloys with pulsed laser beam welding and full automatized wire feeding was investigated. The process was monitored with a high-speed camera to correlate the spatial alignment between the pulsed laser beam and the wire tip. Careful tuning of the wire tip position relative to the melt pool was necessary in order to enable stable welding conditions.

Acknowledgements

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