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Parallel robot platform for freeform laser manufacturing

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Abstract

A novel laser-based freeform manufacturing platform is prospsed with the ability to both add material to, or remove material from, a freeform part and post-process in combination with metrology. The synergy of these processes offers the potential to enable a high level of form fit and low tolerances in excess of that achievable in freeform manufacture alone. Our approach is based on a parallel kinematic robot platform with advantages in terms of accuracy, speed and costs compared to serial robot arms. Fibre-delivered laser sources are integrated into the robot to produce a flexible system capable of several concurrent engineering processes. The additive manufacturing ability is based on blown-powder laser metal deposition. Novel hollow-core negative curvature fibres are utilised for the delivery of high average power picosecond or nanosecond pulses for subtractive laser processing.

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1. Introduction

The manufacture of high value customized parts experienced a signifanct growth in traditional European strongholds in recent years. As a consequence, there the clear requirement to develop novel processes which support the manufacture of such specialized parts and the generation of significant added value. Freeform fabrication is one of the most flexible manufacturing platforms and enables highly flexible design and manufacturing procedures. Exsiting limits of traditional manufacturability can be overcome and a fluid evolution from concept to product can be provided. This technology enables difficult but important geometries and even tailored material. The concept for a novel 3D laser-based freeform fabrication platform that we presente here combines:

- The capability to construct and add material to freeform shapes,
- metrology of the created part, and
- the ability to remove material and post-process the part.

The synergy of these processes offers the potential to enable a high level of form fit and low tolerances in excess of that achievable with individual workstations. The freeform fabrication platform is based on a commercially available parallel kinematic robot (see figure 1) which is used as an automated comparator gauge tool. Parallel robots offer distinct advantages in terms of accuracy, speed and also costs compared to serial robot devices. Fibre-delivered laser sources are integrated into the robot platform to produce a flexible system capable of several concurrent engineering processes. The system includes additive manufacturing based on blown-powder laser metal deposition. Novel hollow-core negative curvature fibres are utilised for the delivery of high average power picosecond (ps) or nanosecond (ns) pulses for subtractive laser processing and laser polishing.

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Fig. 1. Commercially available parallel kinematic robot platform as a comparator gauge.

Parallel kinematic robots are a well established technology for handling and positioning applications. Additionally, they generated a strong attention for the use as machine tools due to their conceptual advantages in high motion dynamics and accuracy in combination with a high structural rigidity as a consequence of their closed kinematic loops (Weck et al. 2002). A parallel robot design means that the end effector is connected to the base via multiple kinematic chains (see figure 1), whereby any two chains form form a closed loop. This is opposed to classical open loop mechanisms like serial or articulated robots. The conceptual advantages of parallel kinematic robots as a manufacturing platform compared to serial robots include (Tlustly et al. 1999 and Weck et al. 2002):

- High dynamics due to low moving mass
- High stiffness due to closed loop kinematic loops
- Modular and simple frame designs

These benefits, however, also imply drawbacks such as a more complex control and an increased susceptibility to thermal load. Further details on parallel kinematic robots and in-depth discussions of their advantages as a machining platform can be found in Weck et al. 2002 and Smith 2016.

2. Experimental setup

2.1. Fibre delivered subtractive laser processing

The subtractive aspect of this freeform manufacturing platform is based on fibre delivered short pulsed laser processing. High average power ps or ns laser pulses enable tho preparation of the workpiece for a subsequent additive process, e.g. by laser cleaning or the removal of an oxide layer, and the a post-treatment of the additively built or repaired structures, e.g. removel of excess material or laser polishing.

In order to fully utilize the advantages of the parallel robot in terms of speed of movement and precision a lightweight laser processing head is essential. High average power and fibre delivered ps and ns laser pulses typically require an optical isolator to prevent potential damage to the laser source by backreflected laser irradiation. The significant added weight of such a device, typ. > 500 g, would imply restrictions to the performance of the parallel robot. As a solution to overcome this limitation, a novel hollow-core negative curvature fibre (NCF) is utilised for the laser beam delivery. These fibres enable the delivery of sufficient average power for a variety of laser processing applications. Ps pulsed laser machining at a wavelength of 1030 nm and in the ns regime at a wavelength of 1064 nm respectively was published recently without the requirement of an additional optical isolator (Jaworski et al. 2013).

A typical NCF cross-section is shown in figure 2. The fibres are fabricated by a standard stack and draw technique (Yu et al. 2012). The guidance principle is based on the so-called anti-resonant reflection optical waveguiding mechanism (ARROW) and further details on this can be found in Litchinitser et al. (2002).

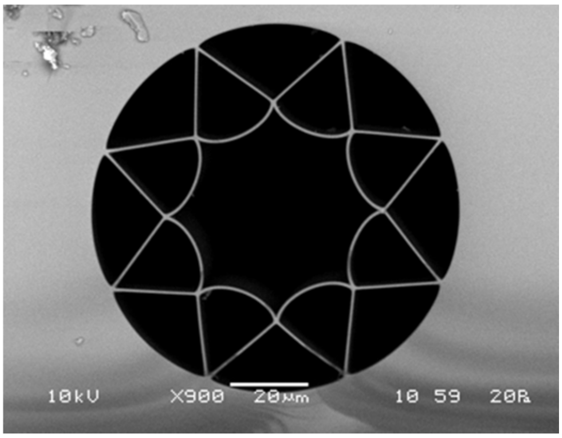

Fig. 2. Cross-section of a hollow core negative curvature fibre (NCF) with a core diameter of 42µm, suitable to deliver high average power ps and ns laser pulses in the near IR region.

A schematic of the lightweight subtractive laser processing head is shown in figure 3. It consists of the NCF to deliver the laser and a short focal length lens to focus the divergent single mode output (NA = 0.032) of the fibre onto the workpiece. The beam diameter at focus is ~40 µm. The low intensity leakage of the laser beam through a delectric mirror is measured with a power meter for closed-loop power monitoring and control. A CCD camera and corresponding optics enable an on-axis inspection and monitoring of the subtractive laser process.

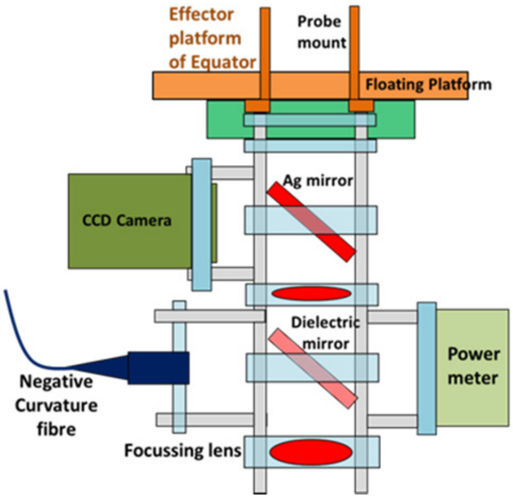

Fig. 3. Schematic of the processing head for ps and ns pulsed fibre delivered laser processing. The power meter and CCD camera enable closed-loop process monitering and control.

2.2. Additive laser processing: Laser metal deposition

The additive processing is realised using laser metal deposition (LMD) based on a blown powder process. Metal powder, typically delivered by an inert carrier gas, is combined with a high power focussed laser beam at close proximity to the work piece to form a melt pool that results in material deposition on the substrate material. The processing head and consequently the interaction zone between powder and laser is moved relative to the work piece to realize the desired geometrical structures for each layer. For more details on LMD please see Gu et al. (2012).

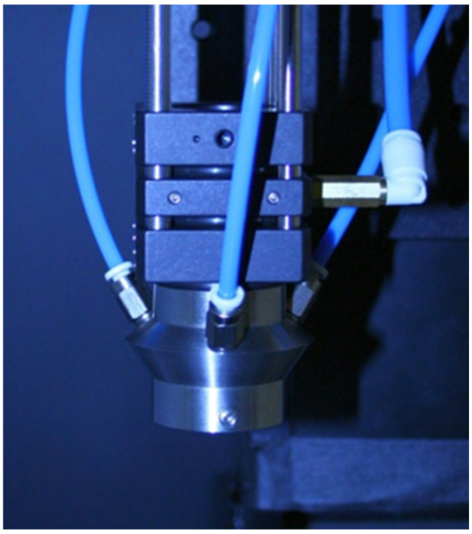

Fig. 4. Additive processing head for laser metal deposition: Coaxial powder nozzle, inlets for powder, carrier gas and shielding gas and focusing optics.

A custom lightweight coaxial powder nozzle was devoloped to deliver stainless steel 316 powder (average diameter 30 µm) onto the substrate by means of Argon (Ar) carrier gas. As before, a low mass of the additive processing head is essential with regards to the high dynamics enabled by the parallel robot. In addition to the carrier gas, Ar shielding gas is delivered for Oxygen depletion at the laser powder interaction zone and to protect the focussing optics. The processing head is shown in figure 4. A cw fibre laser operating at a wavelength of 1070 nm and providing a maximum power of 400 W is used here. The focal position of the laser and the powder is ~ 5 mm below the coaxial nozzle.

3. Results and discussion

3.1. Subtractive laser processing

NCF laser delivery is well suited for high average power short pulsed laser processing (Jaworski et al. 2013). Figure 5 shows typical examples for nanosecond pulsed laser marking and cutting enabled by NCF beam delivery. The laser was operated at a wavelength of 1064 nm with a pulse width of ~ 60 ns and a repetition rate of 15 kHz. The resulting pulse energy was 0.8 mJ. The scanning speed was 1 mm/s for the cutting through 0.3 mm thick Aluminium (figure 5a) and 100 mm/s for the marking of Titanium (figure 5b).

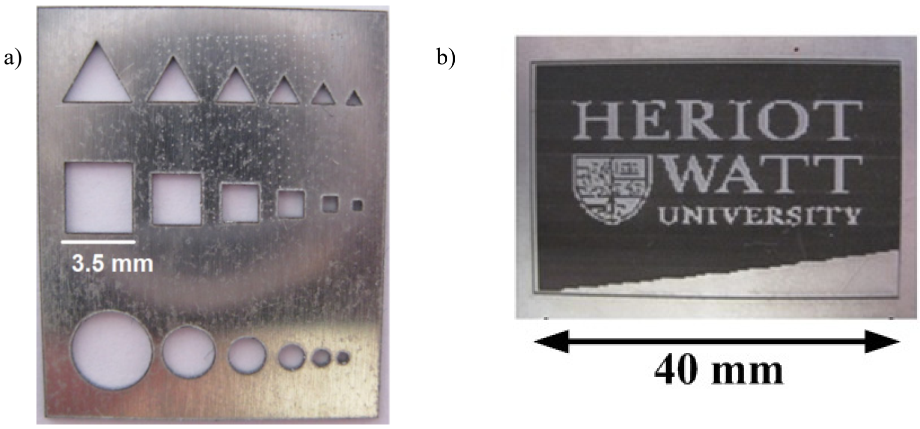

Fig. 5. NCF delivered nanosecond laser processing: a) cutting of 0.3 mm thich Aluminium at a scan speed of 1 mm/s, b) marking of Titanium at a scan speed of 100 mm/s.

3.2. Additive manufacturing

The calibration and optimisation of the powder distribution delivered by means of the coaxial powder nozzle was realized in accordance with Balu et al. (2012). As a demonstration for the precission that can be realized using this custom powder nozzle a “smiley face” structure from stainless steel 316 powder was additively manufactured by means of LMD on a substrate of the same material (see figure 6). The stainless steel powder was transported using Argon gas. Additional Argon was provided as shielding gas. The cw fibre laser was operated at a power of 70 W and the focussed spot diameter was ~ 80 µm. The resulting height of the deposited structure is ~40 µm.

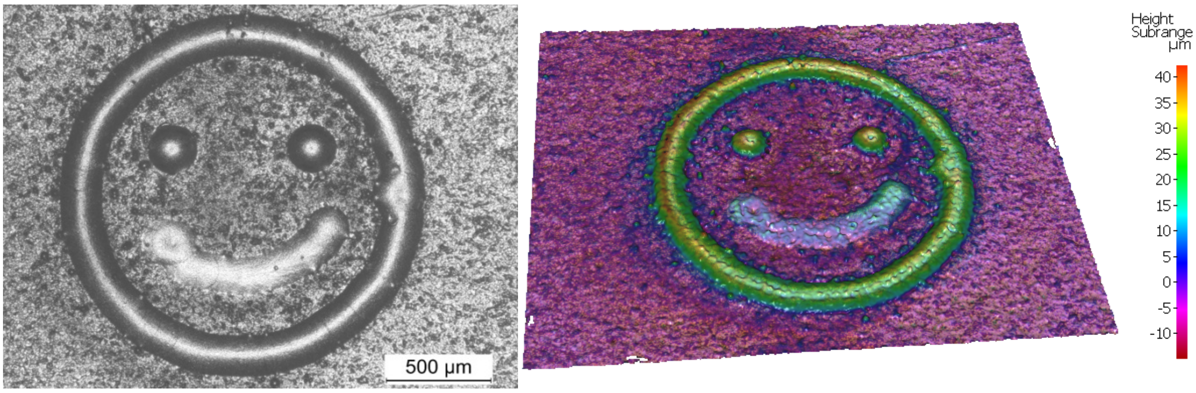

Fig. 6. Additively manufactured example of a "smiley face" from stainless steel 316 powder on SS 316 substrate. The height of the features is ~40 µm: a) shows the sample using a standard microscope. The surface profile in b) was measured using an ALICONA Profilometer.

4. Summary

Overall, the combination of concurrent engineering tasks to a freeform laser-based fabrication platform has the potential to enable new product development and fabrication steps for novel customised parts or the repair of damaged high value components. Additionally, process monitoring and on-machine component inspection can be also provided.

5. Acknowledgement

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