Advanced Research for Manufacturing Systems Laboratory

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Ultrasonic Vibration Study

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1 Introduction

The purpose of this study was to research ways to implement ultrasonic vibration to reduce porosity in DED meltpool. A quick technical background research shows that ultrasound is widely used to improve material properties in metal and ceramic manufacturing techniques. These techniques mostly consists of the material being melted to be reshaped, such as casting and additive manufacturing. The main idea that prompted this study is to evaluate the feasibility of using ultrasound for ARMS LAB's DMG MORI LT65. To determine the feasibility, this study aims to obtain equations and knowledge regarding the following:

- Power needed for degassing in a viscous liquid
- Shaking intensity to move gas bubbles to the top
- Optimal ultrasound frequency
- Clad dimensions

The main assumptions regarding our system is stainless steel particles that are 1mm tall, 3mm wide and 4 mm long ellipsoids [1] that form the metal powder coming out of the nozzle, along with argon gas.

The following section discusses the findings obtained from the most promising papers found during the technical background research regarding ultrasonic vibration use for porosity reduction.

2 Findings and Discussion

Overall, the technical background research did not yield clear results indicating the parameters to be used specifically for LT65. The papers that are found most useful are listed below for any future work that might stem from analyzing these papers further:

- Microstructures and Mechanical Properties of Fe-Cr Stainless Steel Parts Fabricated by Ultrasonic Vibration-Assisted Laser Engineered Net Shaping Process [2]
- Ultrasonic Vibration-Assisted Laser Engineered Net Shaping of Inconel 718 Parts: A Feasibility Study [3]
- Effect of Applied Angle on the Microstructure Evolution and Mechanical Properties of Laser Clad 3540 Fe/CeO_2 Coating Assisted by in-situ Ultrasonic Vibration [4]
- High Power Ultrasonics in Pyrometallurgy: Current Status and Recent Development [5]

The rest of the bibliograpy listed at the end of the document includes sources that might be relevant to any future work regarding reducing porosity in AM process.

The experimental results of three studies that resemble the LT65 setup the most are summarized and tabulated in the following subsections.

2.1 Microstructures and Mechanical Properties of Fe-Cr Stainless Steel Parts Fabricated by Ultrasonic Vibration-Assisted Laser Engineered Net Shaping Process [2]

This article includes an experimental set-up where DED process is done with stainless steel powder and argon shield gas. However, the paper did not include any equations or ultrasound parameters that could be used for LT65.

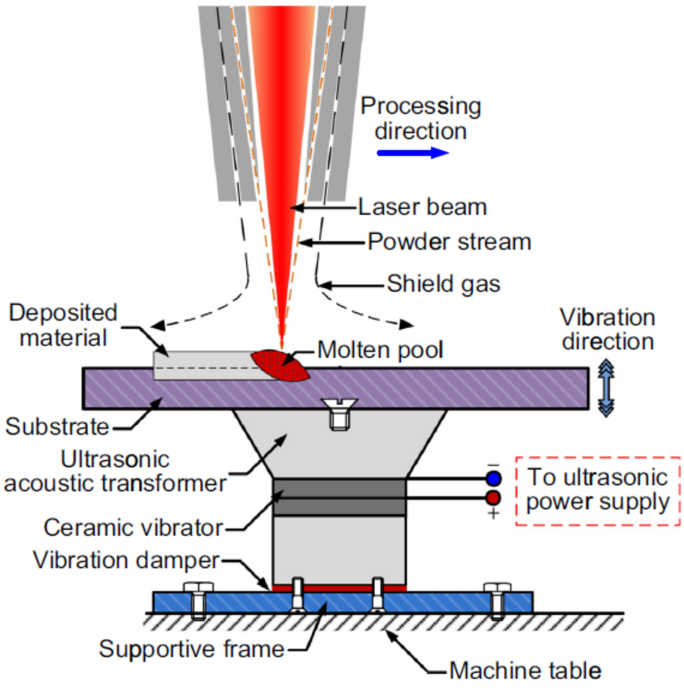

Figure 1: Experimental Set-up for UV assisted DED process. [2]

Table 1: Experimental setup for [3]

AM Machine	450XL, Optomec Inc., Albuquerque, NM, USA
UV Direction	Vertical
UV Generator Type	Piezoelectric ceramic vibrator
UV Frequency	Not provided
UV Power	Not provided
UV Amplitude	Not provided
Substrate Material	Low carbon steel
Substrate Dimensions	100 mm x 50 mm x 6.4 mm
Powder Material	Stainless steel (73.3% Fe, 15.5% Cr (in wt%))
Powder Size	40-105 μm
Clad Dimensions	2.66 mm height (7-layers), 15 mm length
Laser Power	350 W
Nozzle Scanning Speed	500 mm/min
Powder Feed Rate	4 g/min
Argon Gas Flow Rate	6 L/min

The results of the experiment showed that, with ultrasonic vibration, layer cross-section area increased, porosity value decreased, micro-cracks decreased. The mechanical properties of the material also benefited by UV, where the part had a larger tensile strength, yield strength, ductility, and toughness. This can be attributed to the improvements in micro-structure of the manufactured part.

2.2 Ultrasonic Vibration-Assisted Laser Engineered Net Shaping of Inconel 718 Parts: A Feasibility Study [3]

This paper indicated that UV application reduced porosity, refined the microstructure which had a smaller average grain size. It is claimed that these microstructural improvements would further enhance the microhardness of the product when UV is applied [3]. The setup is similar to the previous study, however, this one uses Inconel 718 instead of stainless steel.

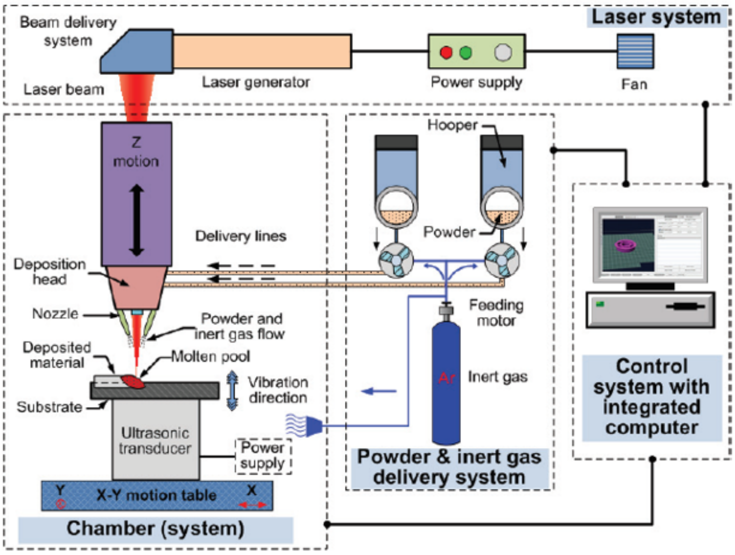

Figure 2: Experimental Set-up for UV assisted DED process. [3]

Table 2: Experimental setup for [4]

AM Machine	450XL, Optomec Inc., Albuquerque, NM, USA
UV Direction	Vertical
UV Generator Type	Ultrasonic transducer
UV Frequency	41 kHz
UV Power	60 W
UV Amplitude	Not provided
Substrate Material	Low carbon steel
Substrate Dimensions	100 mm x 50 mm x 6.4 mm
Powder Material	Inconel 718 (19.28% Cr, 5.04% Nb, 3.05% Mo (in wt%))
Powder Size	45-125 μm
Clad Dimensions	8 mm x 8 mm x 0.43 mm (4 layers)
Laser Power	270 W
Nozzle Scanning Speed	635 mm/min (contour), 508 mm/min (infill area)
Powder Feed Rate	2.63 g/min
Argon Gas Flow Rate	6 L/min

Results are similar to the previous study, where UV overall improves the micro-structure and consequently the mechanical properties of the manufactured part.

2.3 Effect of Applied Angle on the Microstructure Evolution and Mechanical Properties of Laser Clad 3540 Fe/CeO_2 Coating Assisted by in-situ Ultrasonic Vibration [4]

This study evaluates the effect of UV angle applied. The table below includes parameters for the optimal angle.

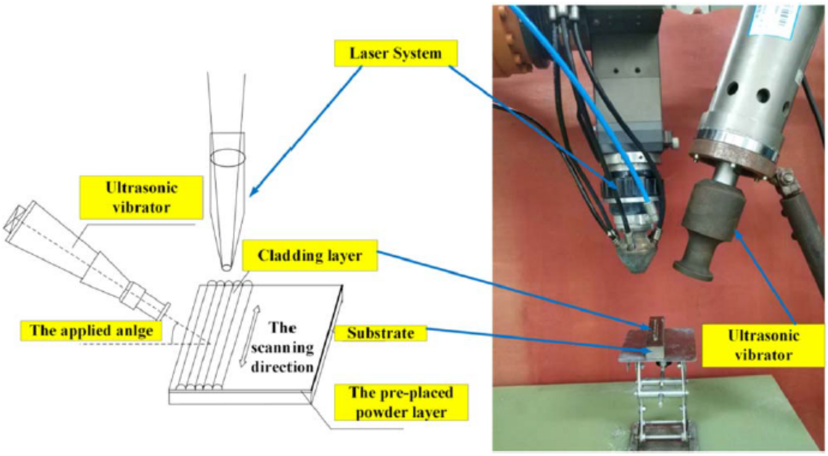

Figure 3: Experimental Set-up for in-situ UV assisted DED process. [4]

Table 3: Experimental setup for [5]

AM Machine	Not provided, FL020 Fiber Laser from Rofin-Sinar Company
UV Direction	45°
UV Generator Type	Not provided
UV Frequency	20 kHz
UV Power	800 W (Maximum)
UV Amplitude	60-70 μm
Substrate Material	42CrMo
Substrate Dimensions	Not provided
Powder Material	3540 Fe/CeO2 (98.8% 3540 Fe, 1.2% CeO2)
Powder Size	70-110 μm
Clad Dimensions	1 mm pre-placed layer height, 4 mm laser beam diameter,
	50% overlapping ratio
Laser Power	1.1 kW
Nozzle Scanning Speed	4 mm/s
Powder Feed Rate	Not provided
Gas Flow Rate	Not provided

This method seems to be preferable because the vibration direction is changeable and only the melting material in the melting area vibrates [5], compared to the vertical setup where the whole table vibrates. So, using a smaller UV device that provides vibration to the melting area is preferred. This way, UV is also suitable for large and complicated parts.

3 Conclusions

Overall, use of ultrasonic vibration improve additive manufacturing and specifically the DED process results in the following:

- Grain size gets smaller,
- Mechanical properties of the material are improved,
- Porosity is reduced,
- Surface friction coefficient is reduced.

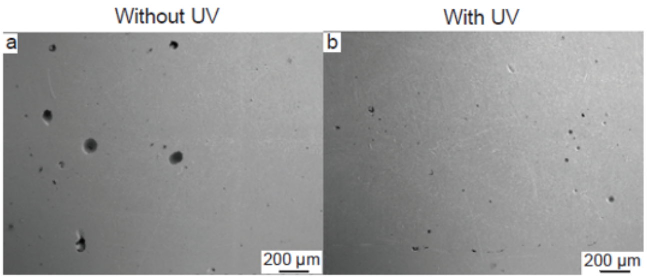

Figure 4: Porosity comparison of workpiece with and without UV. [3]

The best option for the UV setup seems to be the angled UV setup (45 degrees) which provides the ultrasonic vibration to the melting area instead of the entire table. This way, UV can be used for larger parts without requiring more power and can also be implemented in LT65 easier. The specifics regarding implementing UV assist to LT65 AM process wasn't available in the papers researched. However, the tables in the previous section can be used for trial and error method of finding out the best setup.

4 Bibliography

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