ABSTRACT

This paper describes the development of a low cost imaging system used to determine the size of the melt pool created by laser used in Micro Laser Aided Manufacturing Processes (µLAMP). µLAMP is an additive manufacturing process in which metallic material is added to the laser generated heat spot where the metal melts and forms a melt pool which quickly solidifies into metal layers. The size and width of the melt pool need to be constantly monitored for in process quality control to maintain the quality of metal deposited. Conventional cameras and imaging systems get saturated due to the high intensity of light emitted by the melt pool. Off the shelf melt pool imaging systems are extremely expensive to run and maintain. This necessitated the development of a low cost imaging system for the µLAMP system.

INTRODUCTION

Many manufacturing industries require prototyping or low volume manufacturing of parts involved in design of new components. Traditional rapid prototyping methods use parts, typically plastic which are used for conceptualization purposes only and which cannot be field tested in its actual intended function due to inferior strength and toughness properties when compared to metals.

Fig1: Melt pool size of LAMP vs. µLAMP. The LAMP process’s melt pool is 156.25x the area of the µLAMP’s melt pool.
As seen in Figure 1 the melt pool size of the LAMP process is significantly greater than μLAMP. This lead to the decision to use a wire instead of powder [3].

This work concentrates on an imaging system for the Micro Laser Aided Manufacturing Process (μLAMP), which is a miniaturization of the existing Laser Aided Manufacturing Processes (LAMP) [1, 2]. The impetus for the miniaturization was to both lower the cost barrier of entry into metals rapid prototyping and provide facilities for smaller feature sizes than LAMP. Due to the change in scale, μLAMP utilizes a wire feeding system to eliminate the severe material waste that a powder fed process would suffer due to the drastic reduction in melt pool size.

With μLAMP, we can produce complex 3 dimensional fully dense metallic components which can be used directly for its original intended function after minor machining operation. However the laser metal deposition process has many variables such as:

- Laser power
- Laser traverse speed
- Melt pool temperature
- Melt pool geometry
- Filler material and method of addition (wire or powder)
- Base substrate material

All of the above factors constantly affect the size of the melt pool being formed which creates the need for monitoring the process. This work attempts to address an issue associated with quality concerns. Consistent volumetric addition via laser deposition requires some knowledge of the current state of the melt pool. Real-time tracking of melt pool temperature is impossible through contact measurement and difficult via non-contact methods. This work presents an alternative approach which attempts to use the melt pool size rather than temperature to control the process.

BACKGROUND

The laser used in the μLAMP process is a 40 W Dilas diode laser mounted on the movable Z axis with the base substrate being mounted on a XY motion table which obeys commands via a Sanguino microcontroller connected to a computer via an usb port. The filler material is stainless steel 316 wire of diameter 150 µm which feeds into a laser melt pool of diameter 200 µm. Since the margin of error of aligning the wire into the melt pool is very small (± 25µm), there exists a need for constantly monitoring the alignment of filler wire into the melt pool as well as size of the melt pool for optimum deposition. Previous approaches to the problem of imaging the laser melt pool involved a simple filter design to remove the Infrared radiation emitted coupled with a short pass filter to remove wavelength longer than 700 nm [3, 4]. A 300
µm pinhole lens was further used to cut down the signal reaching the CMOS sensor. Figure 2 is the design of the optical fixture which was fabricated using Dimension Fused Deposition Modeler (FDM) which reduced the lead time significantly.

![Fig2: IR filter with pinhole](image1)

The 2\textsuperscript{nd} approach involved using an IR filter and a cold mirror to reflect visible light through a green dichroic filter and a polarized glass disc.

![Fig3: Assembly of the reactive design showing The heat resistant glass (clear), the cold mirror (blue)](image2)
In both the above cases the image obtained was similar to the one shown below

![Image of melt pool with blue, red, and green ellipses indicating fit of ellipse, major and minor axes of melt pool](image)

**Fig4:** Blue ellipse indicated best fit ellipse, Red and green denote major and minor axes of the melt pool.

It is evident that the melt pool is not clearly visible due to saturation of the sensor by the IR radiation. There is also some reflected IR radiation off the laser head. So we decided to implement a different approach which involved using external illumination of the melt pool.

**Illumination Approach:**

The wavelength of laser used in the LAMP process is 808 nm. The wavelength of light emitted from the melt pool is therefore either in the visible region or infrared region of the spectrum. Thus there is no ultraviolet radiation emitted by the melt pool. Figure 5 demonstrates the absence of ultraviolet radiation since the temperature of the black body would have to be infinitely high to generate ultraviolet radiation.
Fig5: The CIE 1931 XYZ Color Space relates black body radiation color and temperature.

(Image courtesy of Wikimedia Commons)

External illumination in the form of 3 UV (390-395 nm) LED’s was aligned such that they illuminate the melt pool. A standard usb microscope with a CMOS sensor was fitted with a narrow band pass filter to filter out everything except incident radiation of wavelength 389-399 nm. The incident UV light is reflected off the melt pool and passes through the narrow UV bandpass and IR filter and shows a clear image of the melt pool.

Fig6: Spectral sensitivity of CMOS sensor is better than CCD in ultraviolet range
Since IR radiation was still able to infiltrate the narrow bandpass filter, an additional narrow bandpass filter was applied along with a heat absorbing glass to remove any remaining infrared radiation. This provided significantly better images in which the track of the laser is clearly seen.

Fig7: Melt pool Image obtained on Stainless steel substrate of .007” thickness

Stainless steel substrate
Melt pool

Fig8: Melt Pool image with 2 narrow bandpass filters + IR filter

Melted and solidified track on substrate
The size of the melt pool was determined using image processing software such as ImageJ. Initial calibration was done using a stage micrometer as a sample.

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CONCLUSIONS

The implementation of the low cost imaging system for determining the melt pool size and condition has been illustrated in this paper. The various difficulties in imaging a high intensity light source have been discussed briefly. The problem of saturating the sensor within the camera remains, despite filtering that should, according to the filter documentation, eliminate all of the infrared radiation. The root cause of the image saturation has yet to be determined, but the control logic of the camera is suspected. The approach to solve this issue would be to bypass the control logic of the webcam and analyze the raw stream of data from the CMOS sensor directly. Thus it is evident that this low cost imaging solution is comparable to expensive commercialized laser melt pool imaging systems.

FUTURE WORK

There is some white distortion in the image whose exact cause is yet to be ascertained. One reason could be the software of the camera trying to compensate the white balance due to the high intensity of the image. The intensity of the UV leds has to be improved by adding more LED’S in the illumination array.

The melt pool monitoring system has to be included as a closed loop control of the laser metal deposition process so that any variations in the melt pool size are detected and automatically compensated for to maintain optimum laser deposition.
REFERENCES


