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FEM Simulation of Melt Pool Formation of STS-410 (Martensite Stainless Steel) for 3D Printing

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1. Introduction

STS-410 material has not been used for 3D printing due to the difficulty of 3D printing. In this study, we tried to find out optimal 3D printing parameters of STS-410 material by FEM simulation. A usual steps of obtaining 3D printing parameter is through single bead experiment and followed by standard specimen porosity elimination experiments. The use of FEM will reduce the repetitive experiments involved in the experiment there by saving time and cost. This study reports the first phase of simulating melt pool formation of single bead experiment. We expect that the simulation result can be used in the trial and error method of finding machine specific actual 3D printing parameters. It is customary that the initial single bead 3D printing experiment of all possible permutations of possible scan distances/scan speeds/laser powers need to be done and analyzed to find out the optimized build parameters. It is very time-consuming and costly, and it can result in wasted metal and damaged re-coater blades. We can dramatically reduce this trial and error process by simulating AM process by FEM methods. In this study, ANSYS Additive Science was used to optimize the AM parameters. Using STS-410 material properties, single bead simulations were performed by a variety of laser power and scan speed permutations. The optimal parameters was determined based on the melt pool characteristics such as melt pool depth, width, length, etc.

2. Methods and Results

2.1 Single Bead Parametric Simulation

$$E = \frac{P}{v \cdot h \cdot t} (J/mm^3) \quad (1)$$

The energy density(E) is a variable related to laser power(P), scan speed(v), layer thickness(t) and hatch distance(h), as shown in Formula (1). Melt pool size is proportional to this. In this experiment, one scan line can be interpreted by inputting laser power, scan speed, layer thickness, base plate temperature, laser beam diameter, and material to be used. The melt pool shape (length, width, depth) can be predicted as shown in Fig 1.

If the scan speed is slow, the depth of the melt pool becomes deeper and a keyhole occurs, and if the scan speed is fast, a Lack-of-Fusion occurs where the metal powder does not melt. Also, when the laser power and scan speed exceed a certain level, bowling occurs.

To solve these problems, appropriate scan speed and laser power are determined based on melt pool characteristics such as Number of Fused Layers, Depth to Width Ratio, and Length to Width Ratio.

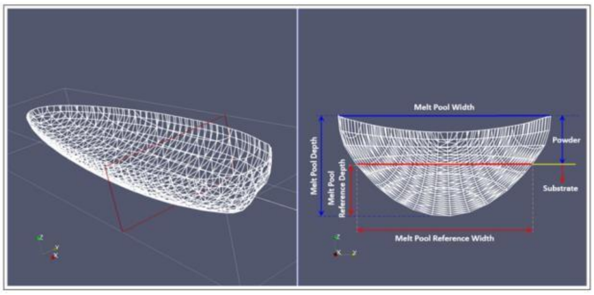


Fig. 1. Results of single bead simulation

Data on the results of the simulation are provided in excel files with individual permutations showing progress information over bead length, and a summary file of the mean and median of the melt pool size for each permutation. By observing and selecting each parameter of an acceptable range in the provided file, the desired optimal range can be acquired.

In ANSYS, as a reference of the empirical optimal melt pool shape, Melt Pool Depth is more than 2.5 times the layer thickness, melt pool depth to Width ratio is less than 0.95, Melt Pool Length to Width ratio is presented only less than 4.0. The length of the bead to be interpreted can be set arbitrarily, and ANSYS suggests that, empirically, the melt pool reaches a stable state when set to 3 mm. The mesh size is set to 15 μm for Single Bead simulations. This value is provided fixed to a value that exhibits good results in terms of accuracy and simulation speed.

2.2 Analysis Objectives and Conditions

For our analysis, the target value of the single bead parametric simulation was set as the range within the optimum melt pool shape standard provided by ANSYS as shown in Table I.

Table I : Objectives of Melt pool shape

Number of Fused Layers	2.5
Depth to Width Ratio	0.95
Length to Width Ratio	4.0

The conditions used in this simulation are shown in Table II. The single bead parametric simulations using

STS410 material properties are performed in 8 cases with a laser power of 100 to 170W at a 10W interval and 8 cases with a scan speed of 500 to 1200mm/s at a 100mm/s interval. A total of 64 combinations were performed. The base plate temperature, layer thickness, and laser beam diameter were set according to the specifications of the equipment to be used.

The bead length is 3 mm long, which is the length of the melt pool to reach a stable state, and the bead on powder layer type is a method of scanning the laser after stacking a layer of metal powder.

Table II : Analysis Conditions

Material	STS410
Bead Length	3mm
Bead Type	Bead on powder layer
Baseplate Temperature	20℃
Layer Thickness	0.030mm
Laser Beam Diameter	0.045mm
Laser Power	Start : 10W End : 170W Step : 10W
Scan Speed	Start : 500mm/s End : 1200mm/s Step : 100mm/s

2.3 Analysis Results

The simulation results were reviewed in two ways: the size of the melt pool (depth, width, length) and the shape criteria of the melt pool (number of fused layers, depth-to-width ratio, length-to-width ratio).

2.3.1 Melt pool size

Figures 2, 3 and 4 show the simulation results of the melt pool depth, width, and length at different laser powers and scan rates.

At a fixed laser power, as the scan speed increases, the depth and width decrease and the length increases. At a fixed scan speed, as the laser power increases, the depth and width increase and the length decreases.

The length is found to be more sensitive to the laser power than the scanning speed. For example, at a laser power of 100 W, as the scan speed doubles from 500 to 1000mm/s, the length changes by 4.84%, but as the laser power increases by a factor of 1.7 from 100 to 170W, the length changes by 33.6%.

Depending on the laser power/scan speed, the depth and width aspects are the same but the length aspects are different, so it is important to find a value that satisfies all three criteria.

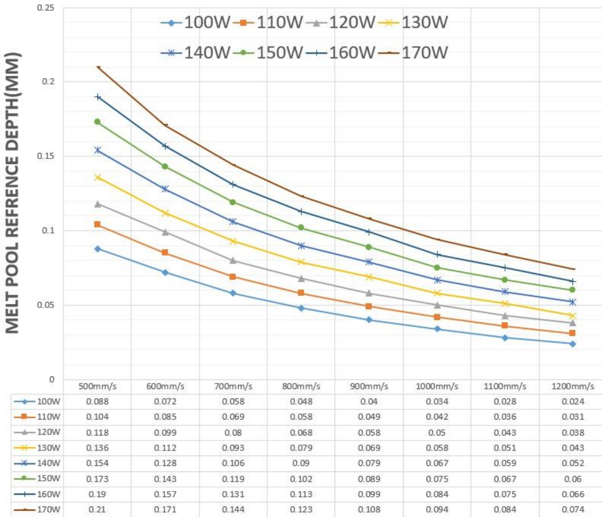


Fig. 2. Melt pool reference depth according to laser power and scan speed

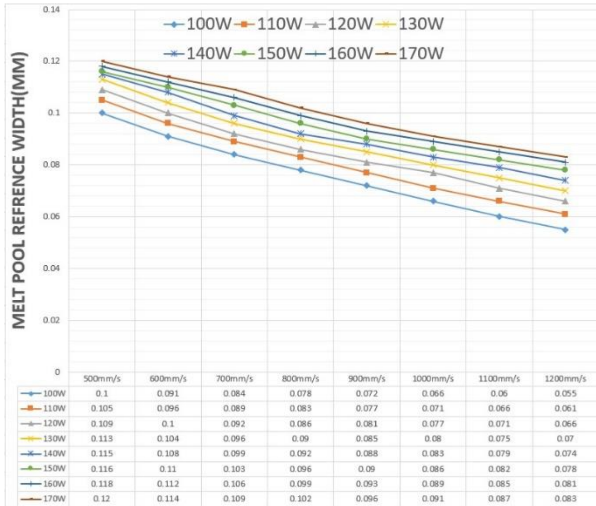


Fig. 3. Melt pool reference width according to laser power and scan speed

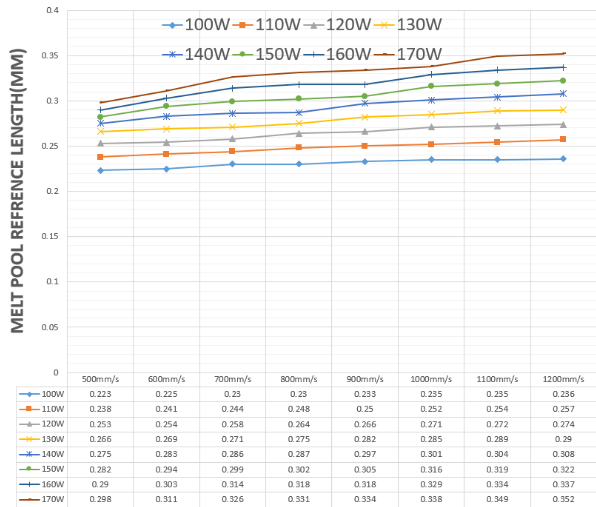


Fig. 4. Melt pool reference length according to laser power and scan speed

2.3.2 Melt pool shape

Figures 5, 6, and 7 show the number of fused layers, depth-to-width ratio, and length-to-width ratio according to the laser power and scan speed, which are variables related to melt pool shape.

The target value of the single bead parametric simulation was set within the optimum melt pool shape standard provided by ANSYS as shown in Table I, and is shown in red in the figure 5, 6, 7.

At a fixed laser power, as the scan speed increases, the number of fused layers and depth-to-width ratio decrease and length-to-width ratio increases. At a fixed scan speed, as the laser power increases, all three value are increase. It is important to find a value that satisfies all three criteria.

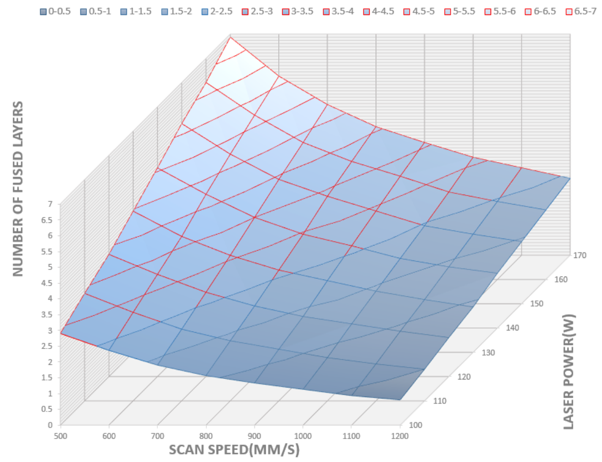


Fig. 5. Number of fused layers according to laser power and scan speed

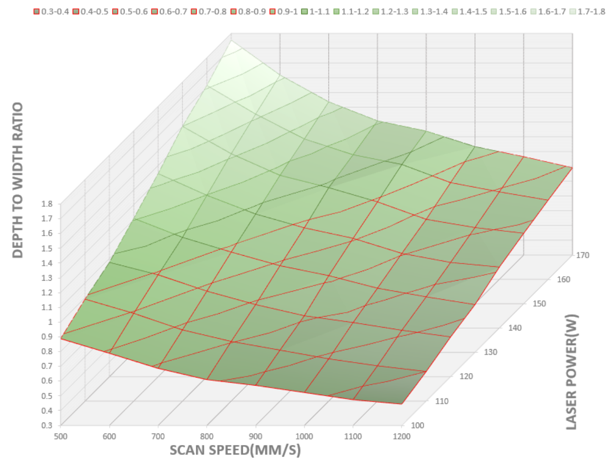


Fig. 6. Depth to width ratio according to laser power and scan speed

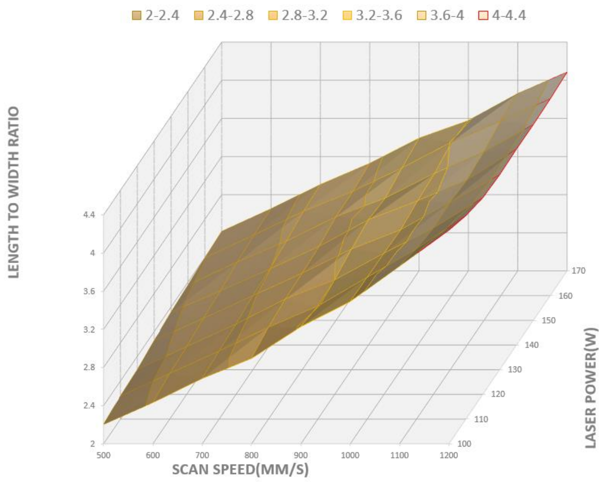
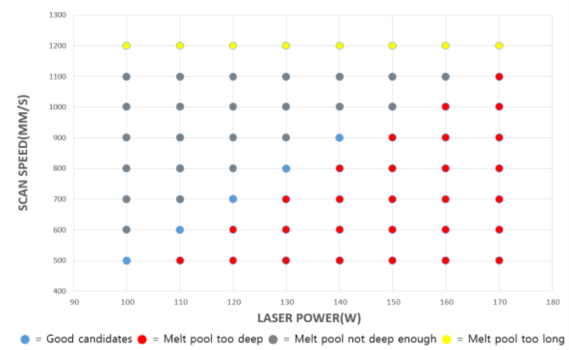


Fig. 7. Length to width ratio according to laser power and scan speed

The five good-candidate laser power/scan speed combinations are shown as blue circles in figure 8. Data points in red are fall outside our acceptable criteria for number of fused layers, indicating melt pools that are too deep. These points locates in a region of the map with low scan speeds and high laser power. Data points in gray are fall outside our acceptable criteria for depth to width ratio, indicating melt pools that are not deep enough. These points locates in a region of the map with high scan speeds and low laser power. Data points in yellow are fall outside our acceptable criteria for length to width ratio, indicating melt pools that are too long. These points locates in a region of the map with high scan speeds.



Laser Power (W)	Scan Speed (mm/s)	Average Melt Pool Reference Depth (mm)	Average Melt Pool Length (mm)	Average Melt Pool Reference Width (mm)	Median Melt Pool Reference Depth (mm)	Median Melt Pool Length (mm)	Median Melt Pool Reference Width (mm)	Number of Fused Layers	Depth to Width Ratio	Depth to Length Ratio
100	500	0.087	0.216	0.098	0.088	0.223	0.1	2.9	0.88776	2.20408
110	600	0.084	0.233	0.094	0.085	0.241	0.096	2.8	0.89362	2.47872
120	700	0.08	0.249	0.091	0.08	0.258	0.092	2.66667	0.87912	2.73626
130	800	0.078	0.265	0.088	0.079	0.275	0.09	2.6	0.88636	3.01136
140	900	0.078	0.285	0.086	0.079	0.297	0.088	2.6	0.90698	3.31395

Fig. 8. Optimal parameter results

3. Conclusions

Using FEM simulation, we were able to figure out how changes in process parameters such as laser power and scan speed affect the melt pool formation. And we could predict a range of additive manufacturing process parameters suitable for materials and equipment to be used.

obtained from the simulation results are suitable when using actual 3D printing. We expect to be able to quickly get optimal build parameters with minimal experimentation in predicted ranges rather than all ranges as before.

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