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Wire + Arc Additive Manufacturing

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Background

Many of today's additive manufacturing processes create parts which are not strong enough to be used in everyday applications, such as for use in automobiles or in the aerospace industry.

Wire + Arc Additive Manufacturing(WAAM) is a process which can create parts made from strong materials, such as aluminum and steel. The wire based method builds a part in the vertical direction by depositing single layers of material in an additive process. This process gives a high level of design freedom, reducing part weight and complexity. Because part designs are not constrained by machine tooling, their designs' can have drastic weight reductions compared to castings, forgings, or subtractively machined parts.

WAAM parts also have much lower rates of material waste, when compared to traditional, subtractive, methods of manufacturing. WAAM also has a smaller environmental footprint than all other additive metal manufacturing methods.

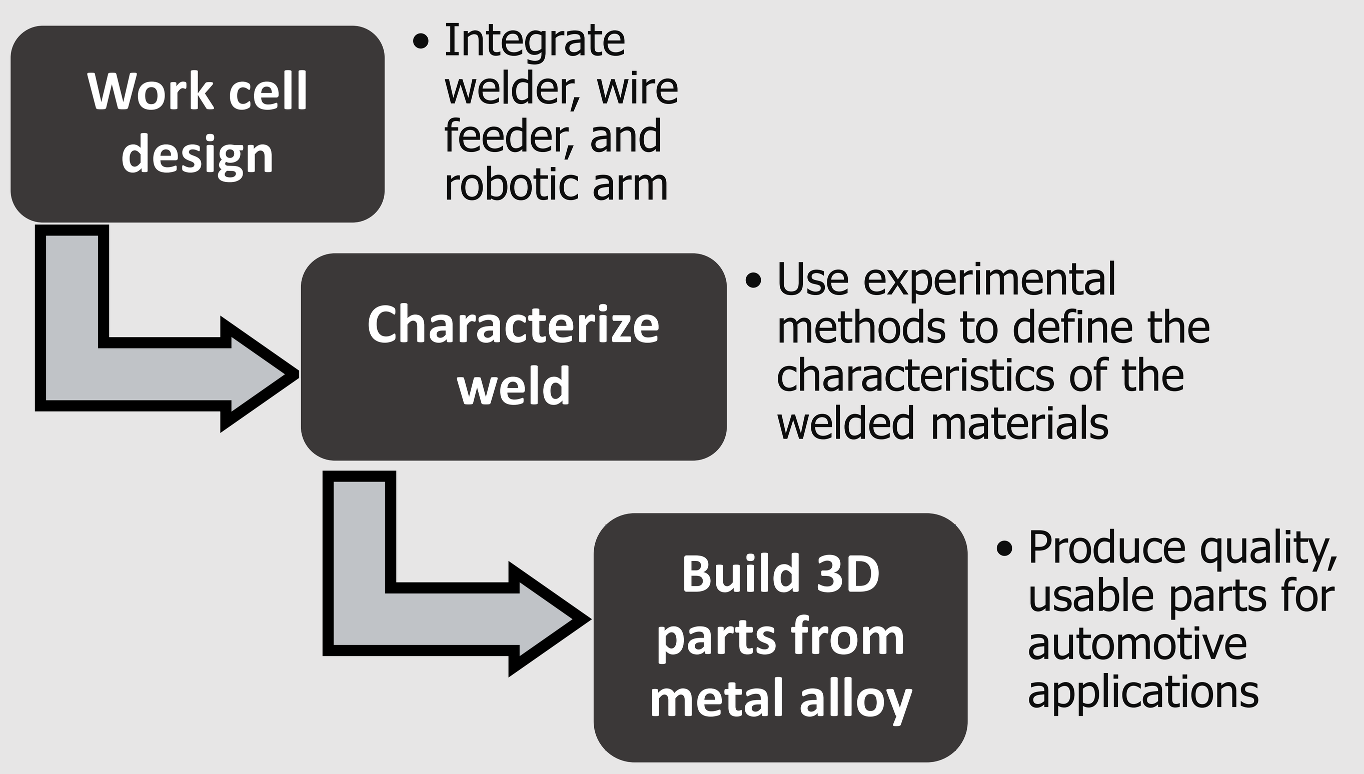
Current Techniques

Most metal additive manufacturing processes use either a laser or an electron beam as the heat source. This heat source is used to melt a filler wire that is fed into the beam, or to sinter a powdered metal.

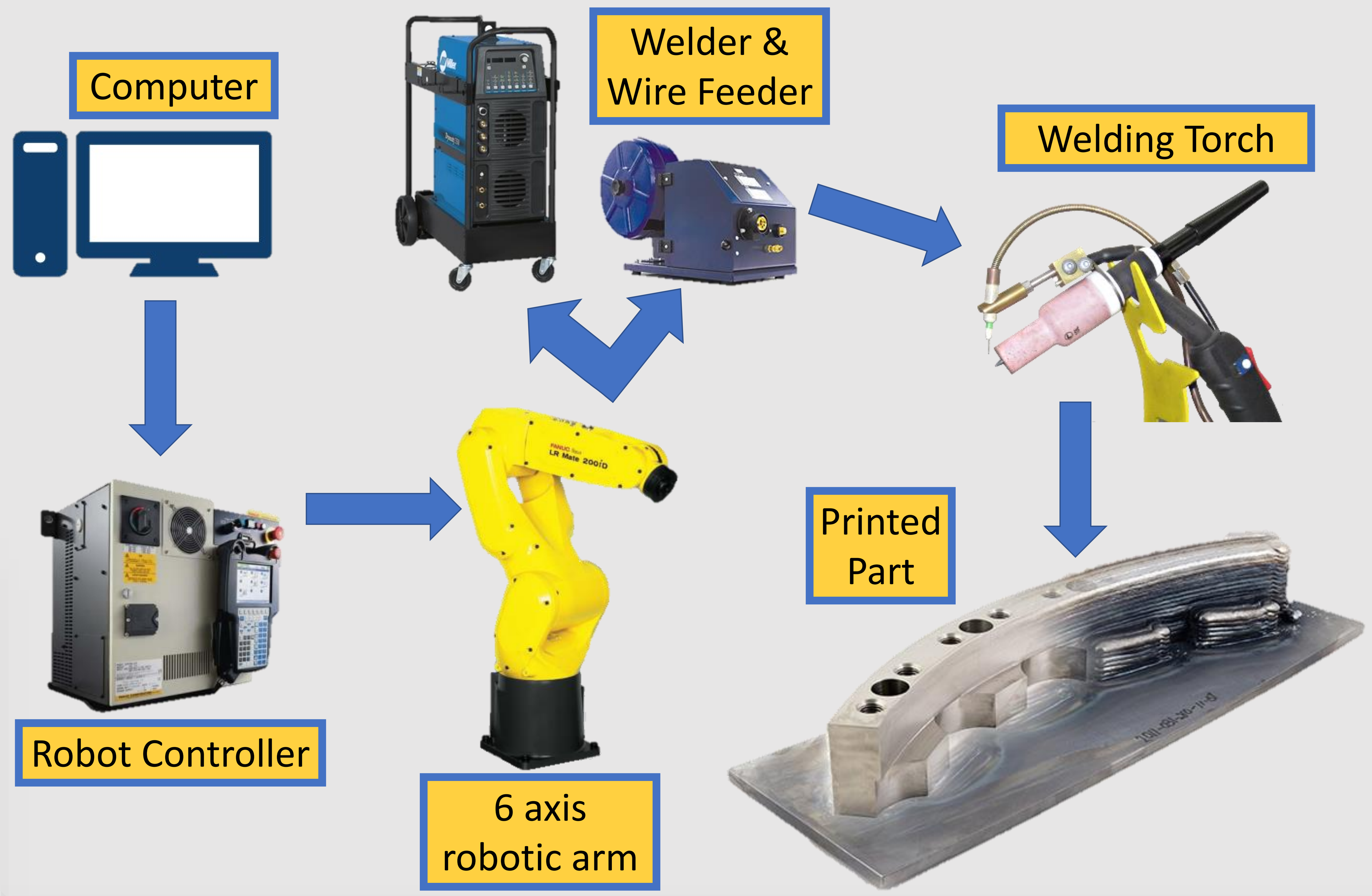
Laser and electron beam wire machines are extremely expensive and are typically only used to manufacture pure titanium parts. Powder additive manufacturing is an extremely time consuming process, sometimes taking multiple days to print parts.

Methodology

The first phase of implementation was to physically connect the welding torch, wire feeder, and robotic arm together. Then the robot was programmed with digital outputs that would control the start and stop of both the welder and wire feeder. The next phase of development focuses around characterizing the material properties of the welded material, using information about the heat input into the system, the efficiency of the welding arc, and ultrasonic thickness measurements. Finally, parts will be printed, starting with low complexity geometric shapes, and scaling up to complex 3D structures.



WAAM Work cell diagram



Work flow description

The architecture of the flow for the wire + arc additive manufacturing process is as follows;

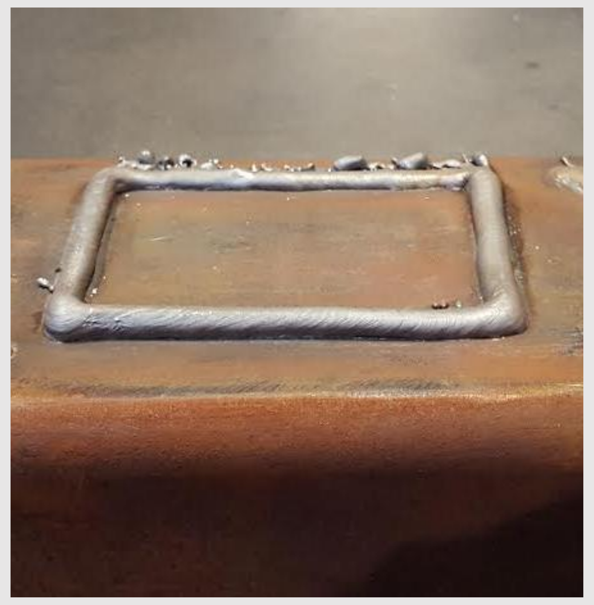
1) A computer aided machining(CAM) software is used to program the toolpaths for the robots and to program the starting and stop points of the welder and wire feeder.
2) The CAM code is converted into coordinate system locations, which are then used by the robot controller to program the robot's trajectory.
3) The robotic arm moves into position, and triggers the welder and wire feeder using 24V output signals.
4) The welding arc is ignited, and shortly after the wire begins to feed into the molten weld pool. Immediately following the beginning of the wire feed, the robot arms moves to the next coordinate using a combination of linear and joint movements.
5) Once the first layer is finished, the welding torch will move vertically by .050"-.075", and the second layer will be printed, repeating this until the part is finished.
6) The part will go through a machining process to get its' final specified dimensions, and clean up any surface roughness.

```
(Trace2)
N0 T1 M6
N5 G00 X0 Y0 Z0
N7 G01 F3 X0 Y2 Z0
N9 G01 F3 X-4 Y2 Z0
N11 G01 F3 X-4 Y0 Z0
N13 G01 F3 X0 Y0 Z.07
N15
%
```

Traditional CNC G-Code to build a square

```
(Trace2)
N0  J PR[1:HOME] 100% FINE
N5  J P[1] 10% FINE
N7  WAIT 3.00(sec)
N9  L P[2] 4mm/sec CNT100
N11 L P[3] 4mm/sec FINE
N13 L P[4] 4mm/sec FINE
N15 L P[5] 4mm/sec FINE
N17 WAIT 3.00(sec)
N19 J PR[1:HOME] 100% FINE
%
```

Equivalent 6-axis teach pendent code



Four layer(.070") square created by WAAM process

Weld monitoring & testing

To get an idea of the material characteristics of the welded part, there are several tests that will be carried out for a variety of welding parameters.

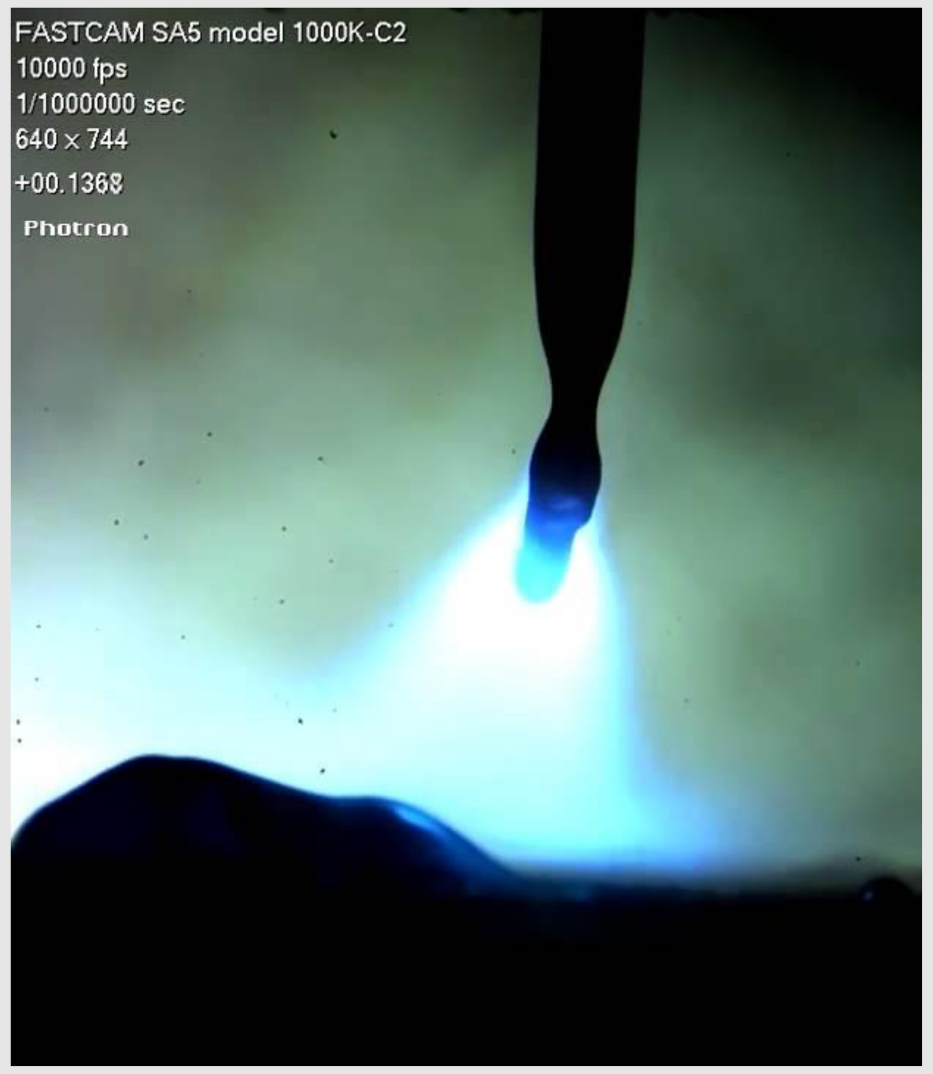
Welding Calorimetry -
The amount of energy input into the work piece will be measured and compared against the amount of electrical energy that is used by the wire feeder and welder. Typically TIG efficiency is low (60-70%), but replacing the traditional filler wire with one that is resistively heated should increase this, making the process more energy efficient.

Infrared Temperature Inspection –
Using an infrared pyrometer, the change of temperature of the metal can be quantified and graphed. The cooling rates of the metal can be refined to prevent rapid cooling which will cause grain sizes to increase, reducing ductility and toughness of the part.

Ultrasonic inspection –
An ultrasonic transducer can be used to test the porosity of the metal. If a part is found to have undesirable porosity the welding parameters can be changed and recalibrated to yield non-porous parts.

Scanning Electron Microscope –
A SEM device can be used to image and inspect the individual grains of the material. These images are the best way to inspect the grain size, grain formation patterns, and the distribution of grain sizes throughout a part. It can also be used to identify the specific chemical composition of the part.

Welding photography –
Using a pulsed laser diode, the actual arc and molten pool of material of the weld can be captured either by a digital camera or by a high-speed recording camera. These images can be helpful in observing the flow of molten metal in the weld pool and also viewing the surface tension of the pool.



Laser diode illuminated welding arc, captured at 10,000 fps