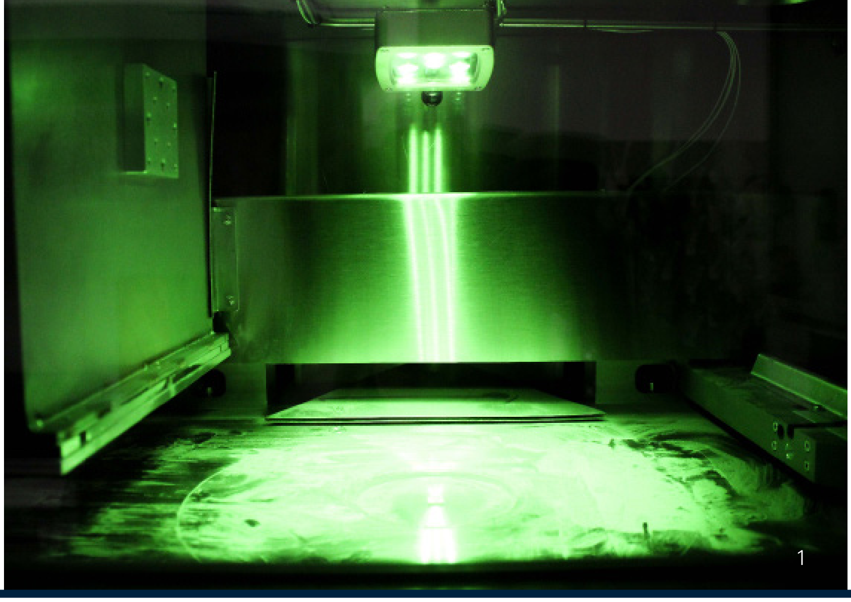
UCONN
INNOVATION PARTNERSHIP BUILDING

A UNIVERSITY-BASED CENTER FOR RESEARCH

PRATT & WHITNEY ADDITIVE MANUFACTURING CENTER

UCONN | SCHOOL OF ENGINEERING



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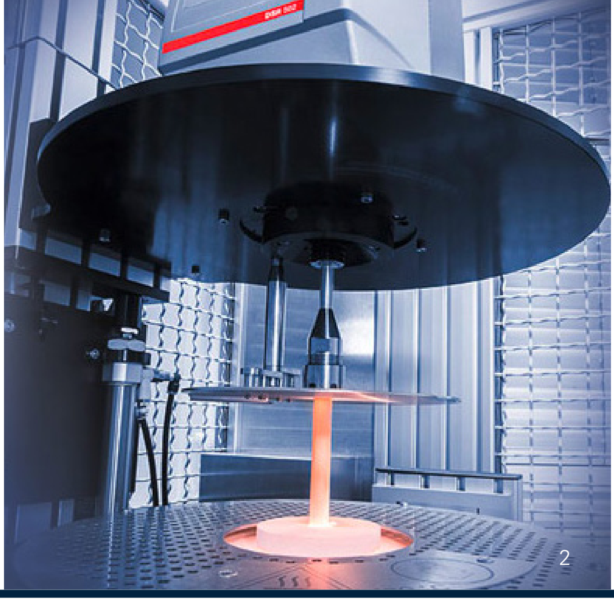
Additive Manufacturing

The Additive Manufacturing Center uses metal powder bed machines mainly for research purposes. The current lineup of machines includes three commercial machines and one custom-built machine. The commercial machines are an Arcam A2X machine, an EOS M270 machine, and a 3DSystems ProX300 machine. Of the three commercial machines our ProX300 machine has been operated with different alloy powders, for example, with 17-4 PH stainless steel. We have used the Arcam A2X machine, so far, with Ti-6Al-4V powder and the EOS M270 machine with IN718 powder. Besides the machine-specific software programs we use Magics by Materialise software to prepare part layouts and support structures. Earlier in 2019 we acquired a custom-built IPG Photonics powder bed machine (Fig. 1). This machine features a vacuum chamber, gas circulation system with soot removal, the ability to use two different alloy powders, and complete access to all hardware and software aspects. Most importantly, the machine can be modified easily, for example with different raking set-ups and blades, custom build plates (four-inch diameter and 12 inch diameter), and an ability to use different gases in the build chamber.

We use our additive manufacturing machines mostly for fundamental studies. These typically focus on processing-microstructure investigations for which we leverage the capabilities of the Thermo Fisher Scientific Center for Microscopy and Microstructure Analysis (CAMMA), located in the same building. Of particular interest to us is the theoretical underpinning of rapid solidification theory for the microstructure and phase formation during additive manufacturing. An additional and more recent focus is for us to examine the high strain-rate behavior of additively manufactured samples.

With our nimble IPB Photonics machine we can furthermore work with relatively small powder quantities to develop new alloys for additive manufacturing. This effort is aided by us using additive manufacturing simulation software to develop machine settings effectively. In order to apply simulation software for new alloys we have to know several material properties and characteristics and we leverage our capabilities highlighted in this brochure to generate many of the required properties.



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Material Data for Manufacturing and for Extreme Applications

Improvements in manufacturing processes increasingly rely on computer simulations. Commercial software has become available for most manufacturing technologies, but a major challenge is the material data that is required for the simulations. We have equipment available in the AMC to analyze the thermal- and thermomechanical behavior of materials.

Calorimetry

A Netzsch 404 F1 Pegasus differential scanning calorimeter allows us to determine specific heats or phase transformations up to 1,500 °C and in controlled atmospheres. Besides the Pt-Rh furnace for this calorimeter, we can also use a graphite furnace for differential thermal analysis to 2,000 °C. While the Netzsch DSC operates at heating rates of typically 5 K/min to 20 K/min, we use a Mettler Toledo Flash DSC 2+ for calorimetric measurements up to 50,000 K/s in heating and 40,000 K/s in cooling and for temperatures up to 1,000 °C. With this instrument we can simulate thermal rate conditions that resemble those found in manufacturing technologies such as casting, machining, or forging.

Thermal Expansion

For thermal expansion measurements, we use two instruments: a TA Instruments heating microscope, ODP 868. The ODP 868 can test specimens from room temperature up to 1,650 °C and it has a maximum scan rate of 100 °C/min that can be limited to lower rates at high temperatures to protect the Pt/Rh heating elements. The ODP 868 measures dimensional changes of samples using four independent high-resolution cameras, i.e., without physical contact with the samples. Besides thermal expansion coefficients, the instrument can also be used for flexure measurements, i.e., pyroplasticity, and for general high-resolution optical measurements of changes in material shape and size during heating. We also use our Gleeble 3500 system with a dilatometer accessory to determine thermal expansion to temperatures of about 1,200 °C using a dedicated dilatometry extensometer with a sub-micrometer resolution.

Thermal Diffusivity and Conductivity

For measurements of thermal diffusivity we use TA Instruments equipment—a 1,600 °C furnace (DLF 1600) and a 2,800 °C graphite furnace (EM 2800). Both furnaces use laser pulses, i.e., flash diffusivity to determine the thermal diffusivity behavior of materials. We have available and have

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1 IPG Photonics research powder bed fusion machine

2 Anton PaarFurnace Rheometer System FRS 1800

3 Detail of the Gleeble 3500 thermo mecanical simulation system

4 Mettler Toledo Flash DSC 2+

used a sample holder for measurements of powder samples that can also be used for liquid measurements at temperatures up to 800 °C.

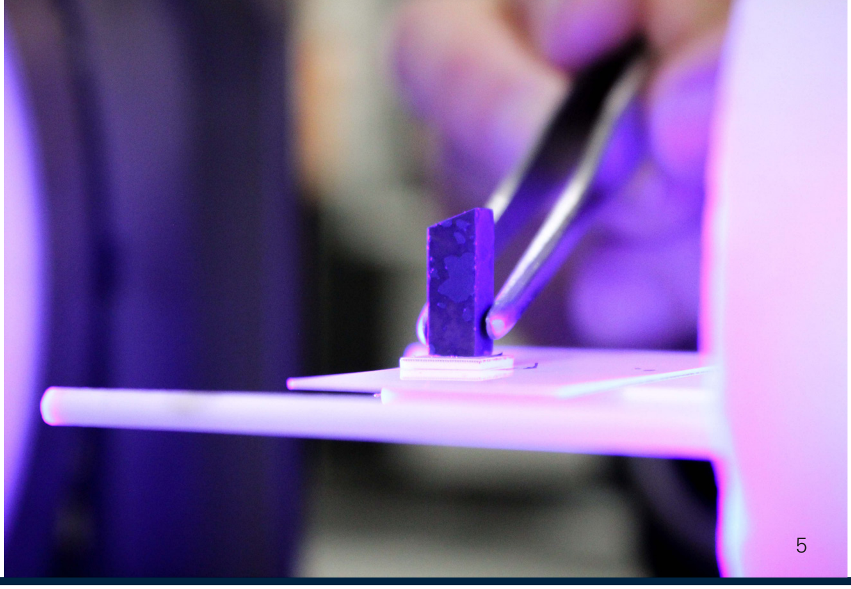
The thermal diffusivity equipment together with our calorimeter and the thermal expansion measurement capabilities can be combined to determine thermal conductivity.

Viscosity

The viscosity of liquid metals and ceramics is determined with an Anton Paar FRS 1800 furnace rheometer. With this rheometer viscosities can be measured up to about 1,700 °C using a cup and rotating bob. We protect the liquid alloys from oxidizing using a mixture of argon and hydrogen gas. Besides continuous rotation measurements we can use an oscillatory mode that yields complex viscosities. The oscillatory mode is particularly useful for measurements in the liquid-solid region, for example, to support thixocasting simulations.

Gleeble System

With a Gleeble system 3500 and our two mobile conversion units (Hydrawedge and High Temperature) as well as several accessories, we cover a broad range of measurements and applications. The primary function of the system is to measure flow stresses and strains of metallic materials. The Joule heating approach enables heating rates up to 10,000 K/s while a very effective cooling system can achieve cooling rates of hundreds of degrees per second. With an active, spray cooling system, we can achieve up to 10,000 K/s in cooling. The system software can be programmed to allow complex test conditions, for example, mechanical testing during heating or cooling, stroke compensation during heating to avoid stresses due to thermal expansion, non-linear test conditions, or strain-controlled testing. With the High Temperature mobile conversion unit, maximum temperatures can be reached of up to 3,000 °C. The Hydrawedge mobile conversion unit allows us to test samples in compression and under multi-hit conditions, for example, for forging simulations. We have developed a good experience base to run high strain rate compression tests under as close to isothermal conditions as possible, for example, for nickel-based superalloys. A host of accessories furthermore allows us to run unique tests such as nil-strength, nil-ductility tests for solidification cracking, solidification studies, stress-induced crack opening tests, or thermal expansion measurements.



Supporting AM Equipment

Powder investigations: We characterize powders in terms of their chemistry, size- and shape distribution, flow behavior, and microstructures. The oftentimes critical content in impurity elements such as oxygen, nitrogen, or hydrogen is analyzed with a LECO ONH 836 instrument. Carbon and sulfur content, for steels, for example, are analyzed with a LECO CS 844 instrument. For the general chemistry analysis, an Agilent 7700 ICP unit will be installed in the near future. To analyze powder size distributions, we use a combination of a Camsizer XT instrument from Retsch and a Thermo Fisher Explorer scanning electron microscope. The Camsizer allows us to examine millions of particles for their size and shape within minutes and the instrument can analyze particles as small as about 10 micrometers routinely. To analyze smaller particles and also to the upper end of the powder particle size range, we resort to an Aspex electron microscope that can measure and analyze particles for both size and chemistry in an automated mode. On the order of thousands of particles can be analyzed within approximately an hour of instrument time.

Our interest in powder extends to characterization of powders and to powder raking. Besides the powder chemistry we have gained experience preparing powders for electron microscopy and can image several particles in one sample preparation step. With a manual offline raking device we can physically and efficiently simulate powder raking and analyze powder bed surfaces and local size distributions. This insight is extended to our IPG Photonics powder bed machine that can be easily adapted with different rake types and materials.

Microstructure analysis: Leveraging the equipment and expertise of the adjacent Thermo Fisher Scientific Center for Microscopy and Microstructure Analysis, we focus on processing-microstructure linkages and have extensive experience with 17-4 PH alloys and other commonly used alloys for additive manufacturing such as Ti-6Al-4V and IN718.

Simulations: Supporting our additive manufacturing research we have available additive manufacturing simulation software from different vendors. Simulations of residual stresses and distortions can be experimentally assessed with corresponding measurements. A key focus of the Center is to generate material data for additive manufacturing and other manufacturing simulation software.

5 Sample positioning for thermal expansion measurement

The Pratt & Whitney Additive Manufacturing Center is a university-based center for research on fundamental aspects of additive manufacturing. The center activities focus primarily on materials science aspects such as rapid solidification, microstructure and phase formation, and alloy development for additive manufacturing. A suite of unique thermophysical property measurement instrumentation supports the research activities.

The Center engages with Government agencies and with industry in a broad range of settings such as traditional research grants, purchase orders, or fee-for service work.

pwamc.uconn.edu

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COVER: Detail of additively manufactured component