SPECIAL FEATURE

Building a CNC-capable metal 3D printing lab

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As metal 3D printing has evolved, it has remained an expensive and proprietary technology for the most part. Several large printer manufacturers dominate the industry. They sell closed systems that force their customers to use their materials and sintering services. They have also been the sole source of education on how to get the best results from their proprietary systems.

As a result, 3D metal printing has been largely out of reach for inventors and educational institutions (see Figure 1).

One group of entrepreneurs recently decided to do something about that. They formed a partnership that aims to provide schools with everything they need to produce metal parts in-house – including equipment, supplies and a curriculum to teach students how to use it. They hope to inspire today's students with what's possible and to arm them with the skills they need to utilize 3D metal printing in the workplace (Figure 2).

The three partners are:

- Levil Technology Corp., a manufacturer of desktop CNC systems for schools,
- Sapphire 3D, a company that builds and sells customized kilns for sintering 3D printed metal parts, and
- The Virtual Foundry, a company that develops and sells plastic impregnated metal filament that can be printed on inexpensive FDM printers.

The birth of the CNC-capable metal 3D printing lab

In 2019, Levil developed the EDU-Mill, a desktop CNC machine to sell to schools, so students can learn basic machining techniques in the classroom. It utilizes a Fanuc or Mitsubishi controller, identical to the ones used by manufacturers on their full-scale machining equipment. Housed on a roll-around cart, the EDU-Mill can be easily moved between classrooms. However, its launch was delayed by the pandemic when schools across the country shut down or transitioned to remote learning (Figure 3).

During this time, Andres Leon, Levil's general manager, began experimenting with metal 3D printing. He explained how hard it was to program a five-axis CNC machine to produce a complex metal part, such as an impeller with curved blades. As he explored metal additive manufacturing, he realized that it could print even the most complex designs in a fraction of the time it took him to program a CNC controller to successfully create it.

It became clear to Leon that this new technology represents the future of manufacturing, and therefore something that students need to learn. He became convinced that a metal 3D printer could be an intriguing addition to his company's portable CNC machining center.

The challenge was that existing metal 3D printing platforms were so expensive that they weren't affordable by most schools. Also, their manufacturers required customers to use their proprietary filaments and to outsource sintering to their approved network of suppliers. He envisioned an open platform that would enable students to learn and experiment at an affordable cost.

As Andres and his wife Michelle explored potential suppliers for kilns and materials, they discovered Sapphire 3D, owned by David Lawson. A Chicago-based inventor, he figured out a way to adapt kilns used for firing metal clay ceramics to sinter 3D printed metal parts. He formed a business selling two sizes of kilns to a budding market of artisans and inventors.

Sapphire 3D is a distributor of The Virtual Foundry's metal filaments, which made it a perfect partner to supply materials to the joint venture. Inventor Brad Woods has developed and

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FIGURE 1
EDU-Mill.

refined a set of plastic-impregnated metal, glass and ceramic filaments that can be printed on low-cost FDM/FFF 3D printers – in effect, creating an open architecture market for 3D metal printing.

A shared vision for what's possible

When the three partners met for the first time in person in a chilly Chicago garage in February of 2021, they realized they shared a common vision: to democratize metal 3D printing by bringing it within reach of schools. They saw an opportunity to create a turnkey system that could be used to affordably train the next generation of engineers and inventors in today's classrooms.

This bundled approach offered several benefits: By enabling students to perform each step of metal 3D printing and post-processing, they could learn from their mistakes – an opportunity that would be lost if parts of the process had to be outsourced to third parties. This level of hands-on learning would be a first for the educational market.

In addition, once students understood the equipment and processes involved, they would have opportunities to imagine and create new types of parts that this state-of-the-art platform would make possible.

3D metal printing: Not as easy as plastic

By now, most vocational schools and secondary educational institutions have 3D printing equipment and the expertise to produce plastic parts on it. But producing 3D printed metal parts is a much more complex and multi-faceted challenge.

First, it requires highly specialized materials – metal filaments that have been impregnated with plastic to make them less brittle, so they can be spooled and fed through a 3D printer. The plastic also acts as a binder to keep "green" parts stable until they can be post-processed.

After a part is printed, it must be processed in a kiln to perform two important steps:

1. Debinding, which separates and removes the plastic binder from the metal at temperatures between 900°F (480 °C) and 1000°F (540 °C), and
2. Sintering, a process where the metal part is heated to a much higher temperature to fuse the metal atoms (from 1600°F for bronze to 2300°F for stainless steel).

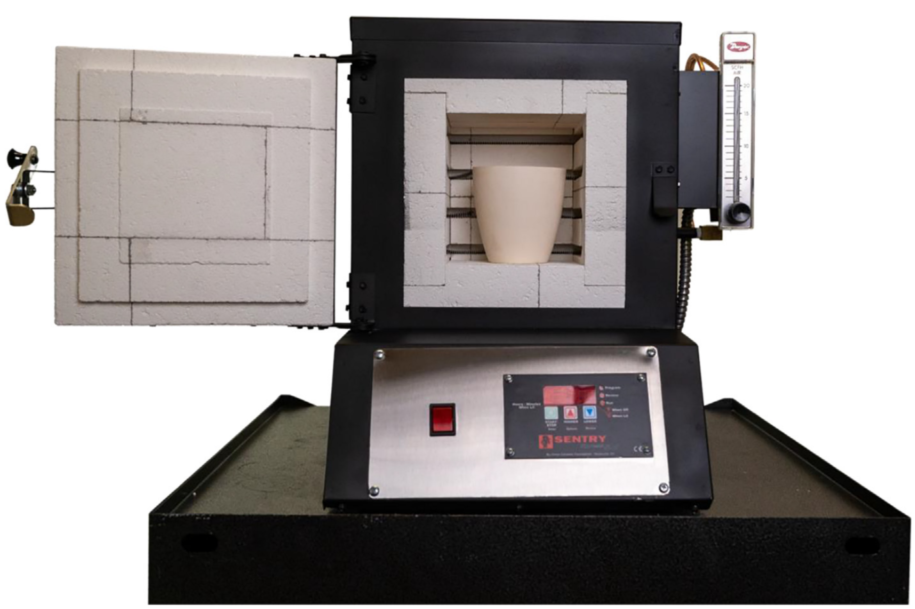

FIGURE 2
Sapphire 3D Oven.

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FIGURE 3

The Virtually Foundry Filament.

All of this requires special equipment and supplies to ensure that the part is properly supported during sintering and to prevent oxidation from occurring, which tends to weaken the metal.

In addition, metal parts shrink an average of 10% to 15% during sintering, a factor that students need to keep in mind when designing and processing their metal parts. In addition, they often require post-processing after printing – such as machining to exact tolerances, applying surface finishes and having holes drilled into them. All of this is a Brave New World for teachers and students.

For schools, it's not enough to have the proper equipment and supplies. They also need a ready-made curriculum that they can teach to students. And all of this needs to be neatly bundled together into a package so that schools can request grants to fund it.

Schools have another option: they can buy printers, sintering equipment and materials on their own. But they risk acquiring a collection of pieces that don't play well together. Plus, what's missing from this ad hoc approach is the curriculum and expertise needed to teach it to students. That's what the teams at Levil, Sapphire 3D and The Virtual Foundry aim to provide.

What's included in this bundle?

Levil supplies the EDU-Mill, a desktop 3-axis CNC machining center that's housed in a steel enclosure that sits on a roll-around cart. It includes all the tooling that enables students to machine and finish metal parts.

It's equipped with a Fanuc or Mitsubishi controller that's identical to the ones used on machine tools in the industry today. This ensures that students will be well-trained to program and operate full-scale machining equipment after they graduate.

Edu-MILL specifications

Machining center

- 3-axis servo-controlled
- High-speed spindle (24,000 rpm)
- Accuracy: 0.0004 in. (0.01 mm)
- Travel on X/Y/Z axes: 7/10.5/5 in. (178/266/127 mm)
- Worktable size: 14.6 × 9.8 in. (370 × 250 mm)
- Rapid feed: 400 Ipm (10,200 mm/minute)
- Cutting feed: 240 Ipm (6,000 mm/minute)

3D FDM printer

- Dual head system
- Build volume: 6.3 × 8.6 × 4.3 in. (160 × 220 × 110 mm)
- Minimum layer height: 0.004″ (0.1 mm)
- Extruder max temp: 572°F (300 °C)
- Heat bed size: 8.6″ X 8.6″ (220 mm × 220 mm)
- Heat bed max temp: 194°F (90 °C)
- Filament size: 1.75 mm

Sapphire 3D offers two sizes of kilns that can be incorporated into this portable manufacturing bundle. Because of the high temperatures these ovens generate, they aren't housed within the EDU-Mill enclosure.

Sapphire 3D also supplies crucibles, which hold the green parts during sintering, and aluminum oxide powder, which covers the parts during the firing process. It provides uniform heating and supports the part as it softens during sintering.

Sapphire 3D also supplies powdered carbon, which is placed on top of the refractory powder to burn off oxygen in the chamber during sintering. This helps to prevent the metal part from oxidizing. In addition, Sapphire 3D supplies all materials needed to polish the finished metal parts

Sapphire 3D kiln specifications

Starter kiln

- Sintering chamber size: 6 × 6 × 6.25 in. (152/152/159 mm)
- Manual gas injection
- Maximum temperature: 2500F/1370C
- 3-button controller

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Pro kiln

- Sintering chamber size: 18 × 18 × 13 in. (458/458/330 mm)
- Programmable gas injection
- Maximum temperature: 2500F/1370C
- Touch screen controller

Sapphire 3D's kilns perform two post-processing operations in a single cycle to transform green metal into finished parts: They first heat the part to a high enough temperature to debind the plastic from the metal. It turns into a gas and is vented out of the kiln. Next, the temperature inside the kiln is increased to sinter or fuse the molecules of the metal parts. All of this is done in a single cycle, making the kilns easy to operate.

By comparison, some debinding processes require the use of solvents and multiple steps to create a finished part.

The Virtual Foundry provides three 1 kg rolls of its copper, bronze and 316L stainless steel Filamet™, plus a Filawarmer (which makes it more pliable before it enters the 3D printer) and a printer nozzle cleaning kit. These materials are easy to use compared to other FFF metal filaments and are much easier for schools to handle than materials used in powder-bed 3D printers.

Why combine 3D metal printing and machining in a single package?

Within the world of manufacturing, there's a strong perception that additive and subtractive manufacturing are opposing technologies. East is east and west is west – and never the twain shall meet.

Actually, the two technologies can be used together in several practical ways:

To machine near-net parts produced using 3D printing to net size: One of the challenges of metal 3D printing is that the sintering process is more of an art than a science. In other words, parts don't experience a precise amount of shrinkage during sintering. Typically, they shrink between 10% to 15% in size. That's why it's often advisable for students to print a part to a near-net size, and then machine it to the exact size and tolerances required.

To finish holes that were partially formed during the 3D printing process: In some cases, students may design a part with a hole that is smaller than what's needed in the finished part, and then machine it to its final diameter. This is especially valuable if the hole needs to be threaded or where precision is extremely important.

A perfect example is a shaft hole for an impeller. An accurately drilled hole is critical to a properly balanced impeller because it must spin at thousands of RPMs without vibration. It's nearly impossible to 3D print a perfectly balanced and finished hole, but this can be done quite easily in a CNC machine.

If one or more surfaces of the part need special finishing: In some cases, one surface of a part may need to have a special finish applied to it. In other cases, one or more surfaces may need to be extremely flat. In both cases, it's best to print a part with a bit of extra material on those surfaces that can be machined to meet the final specifications and tolerances required.

How a desktop printing and machining center can speed prototyping

Because this bundle can handle all the part processing and post-processing in-house, it promises to significantly speed the design and production of prototype parts. Often, engineers need to produce multiple iterations of a new part as they optimize its functionality and appearance.

In a typical school or manufacturing environment, having to send prototype parts to an outside service bureau slows down this process – not only because of the shipping and processing time required, but because the student or engineer may not understand why a part didn't turn out as expected.

Learning happens faster when designers can manage each step of processing and post-processing themselves. Design-build-process-evaluate cycles also happen much faster.

This approach is significantly faster than prototyping cast metal parts. Each time the designer changes a dimension of a part's CAD drawing, a new mold must be built out of metal, silicone or sand to cast it. 3D metal printing and post-processing enables designers to go straight from CAD design to a prototype part, eliminating an entire time-consuming and costly step.

What's next for the printing and machining center?

Levil, Sapphire 3D and The Virtual Foundry are currently conducting webinars to educate teachers about what its metal manufacturing bundle contains and how it can enhance student learning. It has also placed four EDU-Mills with its educational market distributors, so they can become familiar with how to operate it and its capabilities.

Beyond the education market, executives of all three companies see a lot of potential for their CNC-capable metal 3D printing lab to be used in prototyping labs, fabrication labs and R&D facilities – anywhere that can benefit from a compact, portable metal processing center.

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