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METALS YOU CAN AND CAN'T MELT AND 3D PRINT

By Ed [illegible], Editor

There's a growing list of metals that can be laser-melted and "3D printed." But where are the tool steels? There is a pattern here, and it has consequences.

This mold insert is representative of the tooling that can be produced with AM. Despite elaborate internal cooling passages, the insert looks like it could have been conventionally milled or EDMed. *-photo credit Linear Mold*

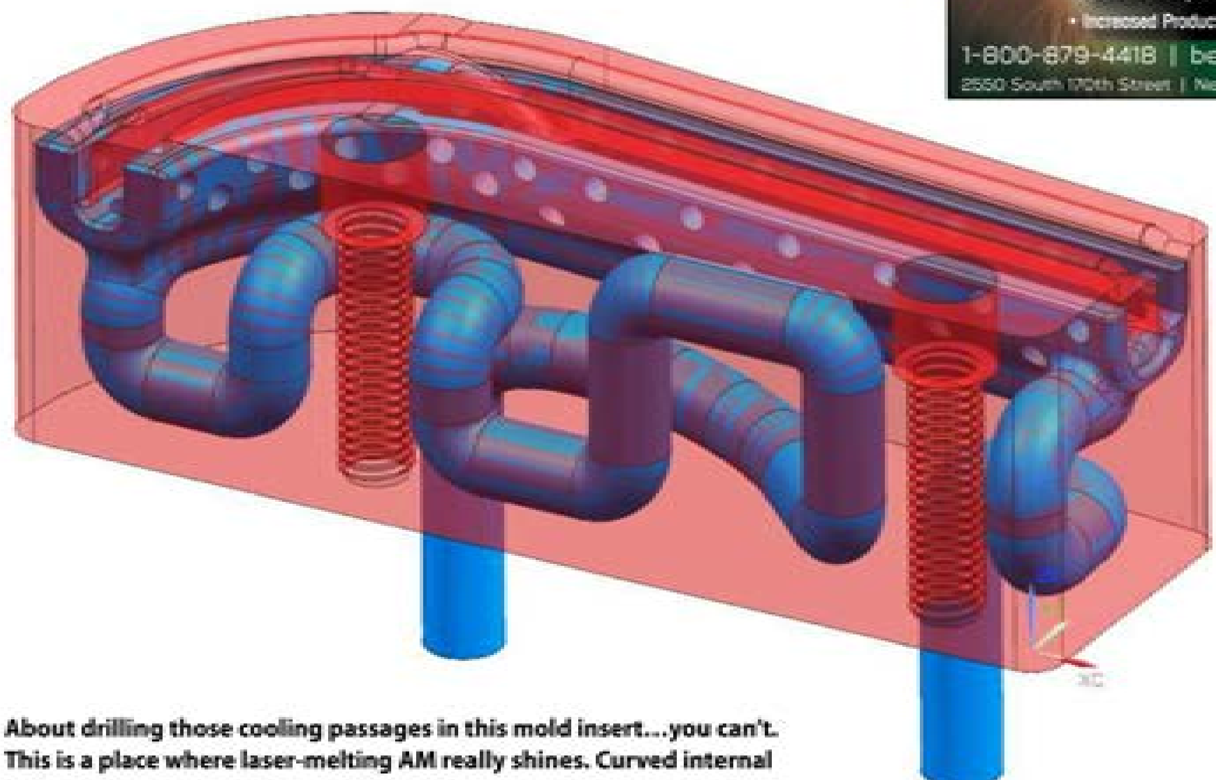
Additive manufacturing (AM) is getting interesting for fabricators. Depending on your specific processes, it may be more than interesting; if you're using any kind of form tooling, or if you make or buy more than a few tools and fixtures, it's on the verge of being compelling. We say that despite our cautious approach to AM.

Both the processes and the materials are developing so quickly that you need a program to keep up. Some of it is a little chaotic and confusing, so let's first clear up a few terms. It gets a little wonkish, so hang on.

We're talking here about AM with metals, for which you've probably seen the terms "direct metal sintering," or something similar that includes the word "sintering." Sintering, or "dry sintering," is a process of heating metal powders to just below their melting point, allowing them to coalesce by means of diffusion bonding.

Carbide cutting tools and some tool steels are made that way. So are some highly-stressed parts, like automobile connecting rods. But they use extra processes to compress and close up the resulting pores, to make the mass nearly 100% dense.

Some of the AM processes produce a similar result, except that there usually is no practical way to compress the sintered workpiece (we'll treat hot isostatic pressing another day). So their density is lower and they have reduced tensile or impact strength, and very low ductility. To make up for this, processors



About drilling those cooling passages in this mold insert…you can't. This is a place where laser-melting AM really shines. Curved internal holes are a snap, even in maraging steel. *- photo credit Linear Mold*

can infiltrate the pores of the sintered part with liquid copper or bronze. The result is quite good, but not perfect.

Lasers are used for sintering, but also, more recently, for actual melting of the powders. This process is sometimes called "direct laser melting." However, at least one large maker of the equipment for this process – EOS – still calls it "sintering." What they do is stronger than dry sintering. Melting, as you would expect, produces a virtually 100% dense part.

It's this latter process that we're following, because of its ability to make high-quality tools of many types. The companies involved with it have compiled quite an impressive list of metals, generally in the form of powders, that can be made into solid objects by 3D laser melting. They can laser-melt

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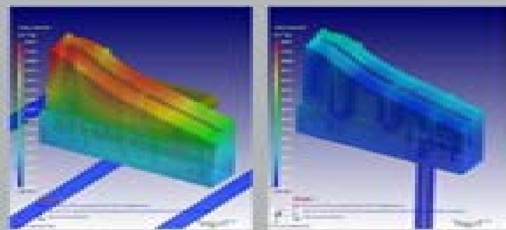

Linear Mold & Engineering (Livonia, MI) builds sophisticated injection molds and other tools using additive manufacturing (AM). They're using direct laser melting with nine different metals, but their big one for high-performance tools is maraging steel.

"It's a good steel for making tools," says Lou Young, director. "It can be hardened similarly to H13 or S7, up to 54 to 56 Rockwell C. It has better corrosion properties than P20 tool steel, and it welds pretty well. We like it especially for injection tools."

Having a steel that's practical for making molds, and that can be direct-laser-melted, has allowed Linear Mold to exploit AM's ability to produce otherwise impossible shapes. In particular, they design internal cooling passages that result in a mold with superior performance.

"In some cases the cooling allows us to cut mold cycle times down 50% from conventionally built tools," says Young. "Improving cycle time anywhere from 20 to 50 percent is huge." The upshot is that AM-produced molds can be up to 50% more productive, justifying a premium price.

The screen shots tell the story. These are thermal-analysis models of tools with conventional cooling (left) and with the AM-produced curved, internal cooling channels (right). The colors show the difference in cooling capability of each design.

"I'm told that our 14 AM machines represent the largest such capability in the U.S. – maybe in the world," says Young. "Some of the largest manufacturers in the country are looking at replacing their conventional molds with these high-performance molds. Things are looking very bright."

Linear Mold & Engineering

some types of steel, precipitation-hardening stainless, aluminum and titanium – it looks like they've covered the field of structural metals. But the list is conspicuous by what it *doesn't* include: high-carbon and tool steels, heat-treatable aluminum grades, and ordinary martensitic (400-series) stainless steels. It appears that the process isn't compatible with high carbon or certain heat-treating behaviors. This, so far, is mostly true, and it's inherent in the characteristics of the process and the behavior of metals that can be heat-treated. It involves rapid melting and an immediate quench, which causes stress and cracking in many of those materials. Some confusion results from the fact that sintering *can* handle those materials, including H13, D2, and A2 tool steels. But, again, if they're sintered, they're not homogeneous and fully dense tool steel.

Back to the laser melting: Big, multinational powder suppliers, such as Nanosteel and Oerlikon, are working on the limitation. Meantime, there are solutions that make laser melting a practical way to make very strong and hard tools, right now. One is to use an expensive, unusual grade of steel that's been around for decades but which has mostly specialized uses: maraging steel. It's used for exotic applications such as components of uranium centrifuges. In the short run, this is our high-performance tool material for laser AM. It can take melting and rapid quenching without cracking. It still has to be stress-relieved and heat-treated to develop its strength, but it can handle the drama. Why that's true is a little too wonkish, but the short story is that it produces iron-nickel martensite, rather than the common iron-carbon martensite, and, unlike iron-carbon, iron-nickel martensite doesn't expand when it's quenched. Wonkishness is now turned off.

Maraging steel has some great properties. It's extremely strong, quite hard (Rc in the high 50s), and especially ductile. One limitation is that it can't hold an edge, so it's not a choice for shears or blanking dies. Otherwise, it can give many tool steels a run for their money. See the sidebar for an excellent example of how this steel and AM can produce superior injection molds.

This pattern of metals that do and don't work with direct-melting AM is similar to the pattern for weldability, for almost the same reason. Grade 2024 aluminum is very difficult to weld – it cracks – and you won't see it in the melting AM list, either. We haven't seen 440C stainless on the lists, but 15-5PH and 14-7PH stainless seem to be okay. Their metallurgical properties, like that of maraging steel, are a little bit odd.

Note that powdered metals can produce alloys that are impossible to make by conventional melting. One long-standing example is the high-end, high-speed steels, sometimes called "transition" materials because their properties exceed those of any ordinary high-speed steel and approach those of sintered tungsten carbide cutting tools. One such is Crucible Steel's CPM Rex-121. It's only possible to make with powder metallurgy.

Expect the Nanosteels and Oerlikons, and other powder suppliers, to work similar magic with powders for direct laser-melting AM. It's only going to get better. And, adding to the complexity, there are intermediate processes, called "liquid-phase sintering" and "partial melting," which produce some different properties and which may be a solution to some of the thermal problem behavior. Following it is like juggling in a moving bandwagon. Don't miss your chance to jump on.

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