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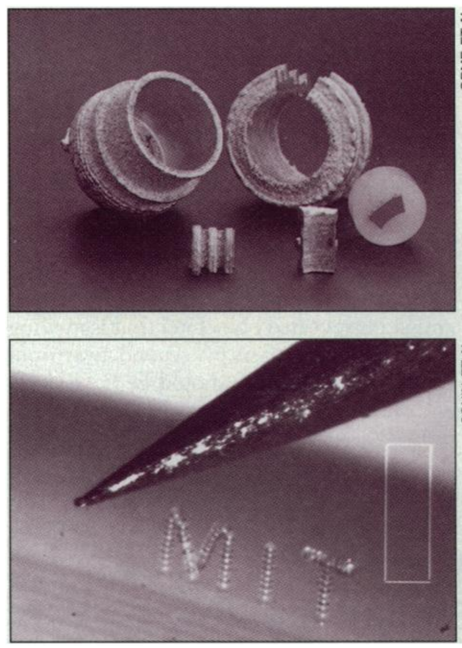
Making Materials That Are Good to the Last Drop

When Massachusetts Institute of Technology mechanical engineer Ain Sonin looks at a common ink-jet printer, he sees the future of American manufacturing. Sonin and a handful of other researchers are utilizing the principles behind such printers to pelt surfaces with molten microdroplets of wax or metals. They are exploring the possibility of what Sonin calls "manufacturing done molten drop by molten drop"—doing everything from simply coating objects to making automobile parts to producing intricate micromotors and gears with the same ease and flexibility as an ink-jet printer builds up letters and characters.

Such applications are mostly fantasy at the moment, but that hasn't stopped Sonin and his colleagues at MIT from forming the Droplet Based Manufacturing Research Program, which has been trying to lure companies like 3M, Hewlett-Packard Co., and Corning Inc. to explore the technology's potential. And MIT is not alone: A group at the University of Southern California (USC) has already patented its own droplet-based system. The approaches vary, but spurring all of them is the prospect of making objects that are stronger and tougher than those made by current practices, such as casting. The strategy should also be far more flexible, says Sonin, since a single machine should be able to lay down drops in any number of three-dimensional microstructures.

First, though, there are plenty of basic challenges to overcome. Indeed, investigators have been struggling with a similar strategy, called spray forming, for more than two decades. In that process, a gas disrupts a stream of liquid metal, creating a spray of microscopic droplets that can be deposited onto a surface to form a coating or a part. The speed at which those droplets solidify is a major advantage, as USC aerospace engineer Melissa Orme explains: "Materials made by rapid solidification have finer grain structure than materials that are cast." And that means better mechanical properties, such as increased strength and impact resistance. But there's a catch: Spray forming has been slow to catch on, since the droplets come out in a variety of sizes and energies, making it difficult to achieve consistent quality.

To overcome these difficulties, researchers have sought a way to make more uniform droplets and maintain greater control over them. And their surprising solution has been a modified ink-jet printer. Ink-jet printers force a stream of ink through a vibrating orifice, which breaks the stream up into droplets of controllable size and spacing that are aimed at a sheet of paper to form letters. To turn the printer into a tool for materials science, Sonin and his graduate student Fuquan Gao load it with wax instead of ink. The wax is heated to around 90° C to melt it and ejected through the ink-jet head in droplets around 50 micrometers in diameter, comparable to a human hair. "The drops then fly through the air, land, and solidify" in microseconds, explains Sonin.



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Drop forged. Minute metal pipefittings *(top)* and 300-micrometer-high wax letters, standing near the tip of a pin.

So far, Sonin and Gao have been using their wax jet to understand basic properties of the wax droplets, such as their surface tension—which governs how much they deform on landing—and the speed at which they lose heat and solidify. "We are at this point only looking at the fundamentals and prospects of the process," says Sonin. The hope is to determine theoretical scaling laws that will come in handy when they reach their goal of replacing the molten wax with liquid metals—first tin and solder, an effort Motorola Inc. will help fund, and eventually higher-melting point metals.

Already, though, the MIT duo have staged some demonstrations of their wax system to show its precision. The two have stacked up microscopic droplets to form towers, arranged them in intersecting lines, and built them up into walls, forming some of the basic structures that might be useful in making futuristic micromachines. By controlling the droplet frequency—the time between successive drops—they can also alter the texture of the result. At high frequencies, for example, individual drops don't have time to harden before the next one lands. As a consequence, the drops merge, producing a seamless tower of wax. In moments of fun, the two have even built the droplets into microscopic wax letters. Their first alphabetical effort was Sonin's initials, but they quickly moved on to MIT—a better public relations move, laughs Sonin.

That virtuosity is facing some tough competition, however, from Orme's group at USC, which is already working with metal to form larger-scale objects. "As far as actually making things, they are far ahead of Sonin," says Steve Traugott, an expert on fluid mechanics at the National Science Foundation (NSF), which funds both groups. He is quick to say, however, that he regards the MIT and USC efforts as "complementary," with Sonin's group exploring the theoretical aspects of drop manufacturing and its potential for microstructures, while Orme's team focuses on developing a technology useful in small part manufacturing.

Instead of relying on a converted printer head, Orme's group has built its own sophisticated droplet generator that can melt and spray materials like Rose's metal, an alloy of bismuth, lead, and tin that has a melting point of around 190° C. With it, the team recently demonstrated the ability to make small, detailed sections of metal pipe. Next, the researchers plan to move up to metals like aluminum. In that effort, Orme's group will be facing some competition of its own. MIT mechanical engineer Jung-Hoon Chun, whose own group has also been working with microdroplets of a tin alloy, is already building the next generation of droplet makers. Chun expects that by the beginning of next year, his newest machine will be able to discharge droplets of copper, a metal that melts at around 1100° C.

Once the technology has been tested with high melting-point metals, industry will take a closer look at it, believes Orme. And that, she says, could be the beginning of a sea change in manufacturing. "It's conceivable that this is a true net-form manufacturing process," she says. By that she means that the method offers the precision necessary to turn raw material into a final form in one integrated step, without the need for polishing, cutting, or other additional measures. If so, an engineer might some day be able to design a part on a computer screen, then "print" it out as a finished object, much as office workers now turn out memos on an ink-jet printer. But even enthusiasts like NSF's Traugott wouldn't bet on it yet. "Where this all will go I have no idea," he admits.

–John Travis