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ENGINEERING

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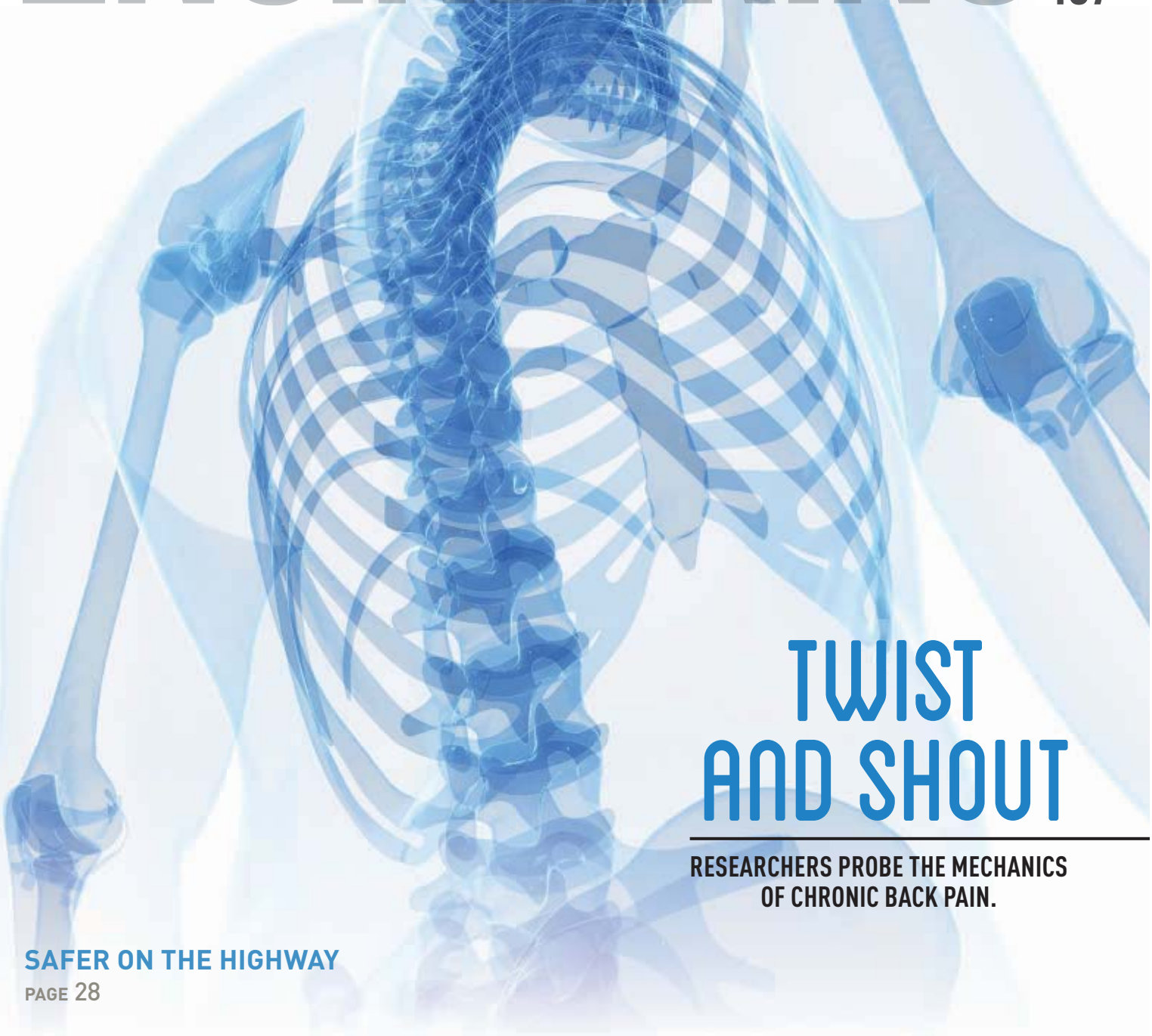
THE MAGAZINE OF ASME

No. 10

137



TWIST AND SHOUT

RESEARCHERS PROBE THE MECHANICS OF CHRONIC BACK PAIN.

SAFER ON THE HIGHWAY
PAGE 28

LOCOMOTIVE BOILERS ARE BACK
PAGE 36

ROBOTS SWIM WITH THE FISHES
PAGE 44

3-D FOOTPRINT GROWS

The largest 3-D printer in the world is the Big Area Additive Manufacturing Machine.

Photo: Oak Ridge National Laboratory

As the range of applications for 3-D printers becomes wider, development times are shrinking while equipment is growing larger. New 3-D printers are getting big, and one now has a build volume of 8 x 20 x 6 feet and a flow rate of 100 pounds an hour of composite thermoplastic material.

The printer's developers, Cincinnati Inc. and the Department of Energy's Oak Ridge National Laboratory, have enlarged their original creation, the Big Area Additive Manufacturing, or BAAM, machine, which has a build volume of 6 x 13 x 3 feet and prints as much as 40 pounds per hour.

The new machine uses a new extrusion system developed by ORNL engineers to reach its print rates of 100 pounds an hour.

The smaller BAAM was demonstrated in 2014 at the IMTS show in Chicago, where over the course of 44 hours it printed all the parts for a Strati, an automobile developed by Local Motors, the custom-car startup based in Phoenix.

BAAM also printed parts earlier this year for a Shelby Cobra.

Most impressive, according to Lonnie Love, group leader of ORNL's Automation, Robotics, and Manufacturing Group, is that engineers developed the Big Area technology over a span of six months.

ORNL signed a cooperative agreement with Cincinnati in March 2014, with the goal of printing a Local Motors Strati vehicle at the International Manufacturing Technology Show in September. "We committed to printing a car with this technology before we had a system," Love said.

ORNL first began work on 3-D printing in 2012 with polymer systems, Love said. The lab's manufacturer demonstration facility is charged to develop new materials and processes, and then move technology to mainstream manufacturing. Love said a wide variety of end users, such as aeronautical firms, visit and work there, looking for an eventual end product.

> **"WE HAD TO FIND THE SWEET SPOT IN THE MIDDLE, AND TRY TO KEEP THE ENERGY INTENSITY AS LOW AS POSSIBLE. THE FIRST TIME WE PRINTED CAR PARTS, THE LAYERS SPLIT LIKE A DECK OF CARDS."**
>
> **— LONNIE LOVE, OAK RIDGE NATIONAL LABORATORY**

Researchers started with refining plastics used in 3-D printing, which were problematic because of variable internal stresses. The first big breakthrough came in January 2013, with the introduction of carbon fiber to the raw plastics. "It was a game-changer," Love said. "You've got these stresses. When you put carbon fiber in, all of that goes away."

The next step was to find a company to build a printer capable of producing large objects. At the begin-

continued on p. 14 »

LICENSE REQUEST FOR WATTS BAR 2

THE TENNESSEE VALLEY AUTHORITY has written to the Nuclear Regulatory Commission to affirm that construction of the Watts Bar Unit 2 nuclear reactor is substantially complete and to request an operating license.

According to the letter, construction has proceeded to the point where the TVA can submit "a substantial number of plant structures, systems, and components to Preoperational Startup Engineering (PSE) for testing."

Testing of the new unit, which it refers to as WBN Unit 2, is continuing, TVA said.

According to the letter, "Hot functional testing has been completed, and the containment integrated leak rate test and integrated safeguards tests are scheduled for completion. The transition plans that were implemented to confirm that the WBN staff is prepared to safely operate WBN Unit 2 are complete. These plans provide reasonable assurance that dual unit operation of WBN Units 1 and 2 can be conducted in compliance with the Commission's rules and regulations without endangering the health and safety of the public."

TVA said that, over a period of eight weeks, operators used the heat generated by plant equipment to increase the temperature and pressure of systems to normal operating levels. The unit's main turbine was also rolled up to normal operating speed using the plant's steam.

It was the first time that nearly 60 important systems functioned together at operational temperature and pressure as designed and built. Important safety-related systems were also tested to show they can help keep the reactor safely cooled. Completion of hot functional testing meets a critical pre-operational requirement for NRC to issue a license, TVA said.

When it comes online, Watts Bar 2 will generate 1,150 megawatts of electricity, or enough to power 650,000 homes.

The full text of the letter and its attachments is available online at http://www.tva.com/news/releases/julsep15/wb2-letter.pdf.

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continued from page 12 »

3D FOOTPRINT GROWS

ning of 2014, Cincinnati executives became interested. The firm manufactured high-speed gantry and laser-cutting systems, which dovetailed nicely with ORNL's preliminary work on large-scale 3-D printers. Within three months Cincinnati developed its first gantry for a 3-D printer.

"Oak Ridge had the concept to use plastics and large-scale extruders and mount on a gantry," said Rick Neff, Cincinnati's head of market development. "We had been asking, 'How do we get involved in 3-D printing?' We make gantries. So it is a little like chocolate and peanut butter."

Scaling up involved some trial and error. Love said most 3-D printers are fairly small machines that work slowly, building parts about one cubic inch per hour for a final product that is usually less than one cubic foot in volume.

Love and his team found challenges in maintaining thermal control. There were distortion and slumping issues with smaller pieces that melted, and bonding problems between layers of large pieces. As the extruder's nozzle lays down material, the greater distances the nozzle must pass for larger parts can allow the material to cool. That causes bonding problems when the next layer is applied.

Oak Ridge lab's Lonnie Love works on 3D-printed Shelby Cobra.
Photo: Oak Ridge National Laboratory

"We had to find the sweet spot in the middle, and try to keep the energy intensity as low as possible," he said. "The first time we printed car parts, the layers split like a deck of cards."

The team now works with standard injection molding pellets heated to 210 °C, at low pressures. "We're not pushing at high pressure. There's not a lot of heat and speeds are moderate," Love said. "Now we can put a lot of material down very fast." Material costs in the range of 3 cents to 10 cents per cubic inch also make printing in large volumes affordable, he said.

Cincinnati's gantries can operate at 200 inches per second, and researchers were tasked with developing an extruder capable of pushing large volume of materials precisely. When the project began, the gantry worked at about one inch per second, applying 10 pounds per hour of material through a 0.3-inch nozzle. At that rate, it would have taken over a week to print the parts for Local Motors' Strati.

Love says two weeks before they were scheduled to print the car parts, ORNL engineers perfected a new screw that pushed the flow rate to 40 pounds per hour, pushing the gantry speed to four inches per second, and cutting down the time to print the car to 44 hours. Researchers are now experimenting with different nozzle sizes and speeds. Local Motors has already said it will leverage the technology and open two car printing facilities, one in Knoxville, Tenn., close to ORNL.

According to Neff, Cincinnati has produced five machines so far, and sold three of them. "This is so revolutionary," he said. "When we were printing the car at the IMTS show, people were looking at it and were wowed. But they weren't saying, 'I have the perfect application for this.' "

Neff and Love believe the technology will have impact in producing machine tools and industrial molds. "The killer application is going to be in tooling," Love said. "If you can make a mold in one day for $1,000, it will be a game changer for the manufacturer." **ME**

JOHN KOSOWATZ, ASME.ORG

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