trons to hop from one grain to the next down the wire. The IBAD method, developed by researchers at Los Alamos National Laboratory and Fujikura Ltd., applies a pair of ion beams to a crystalline compound as it grows on a metal substrate, stripping away misaligned grains one by one to create an oriented template for YBCO deposition. The Oak Ridge team, led by Amit Goyal, David Norton, Donald Kroeger, and John Budai, realized they could speed things up a great deal if they could pattern the underlying metal substrate directly.

They hit on the notion of running a metal, such as nickel, between two rollers: It's long been known that the rolling and heating process allows metal grains to minimize their energy by aligning in the direction of the rolling. Putting this simple idea to work wasn't as easy as it sounds, however. For one thing, oxygen atoms from air tend to coat the nickel surface, disrupting the carefully prepared texture and the alignment of any crystals grown on top. For another, nickel atoms have a nasty habit of trading places with copper atoms in YBCO, destroying its ability to superconduct.

To get around the oxygen problem, the researchers used a technique known as electron beam evaporation to lay down a thin sheet of palladium atop the nickel. Palladium, explains Norton, has a nonreactive electronic structure, so it doesn't attract oxygens. And to keep the nickel from swipping YBCO's copper, the scientists used high-speed growth techniques to lay down two more buffer layers—made of cerium-oxide and yttria-stabilized zirconia—on top of the palladium. The templating effect of the nickel propagates through all these layers to the YBCO layer on the top.

When the researchers tested their sample at 77 kelvin, it conducted 300,000 A/cm^2 in no magnetic field and 15,000 A/cm^2 in a 4-tesla magnetic field oriented in a way that severely damages a superconductor's ability to carry current. In a 4-tesla field oriented in a more forgiving direction, they reported that a YBCO wire with a somewhat different buffer-layer architecture conducted 385,000 A/cm^2. (They declined to give further details of the new high-powered structure until they patent it.)

Using their new rolling technique, the Oak Ridge team has already shown that they can make 1-meter-long metal strips with uniform grain alignment. Moreover, says Goyal, "there's no intrinsic limitation for making long samples." There is an extrinsic limit, however: cost. At this point, the buffer and YBCO layers need to be grown in a vacuum, which makes for expensive manufacturing facilities. The speed, however, may make it the most cost-effective way of rolling out high-powered wire.

–Robert F. Service

PLANETARY SCIENCE

Are Asteroids Flying Piles of Rubble?

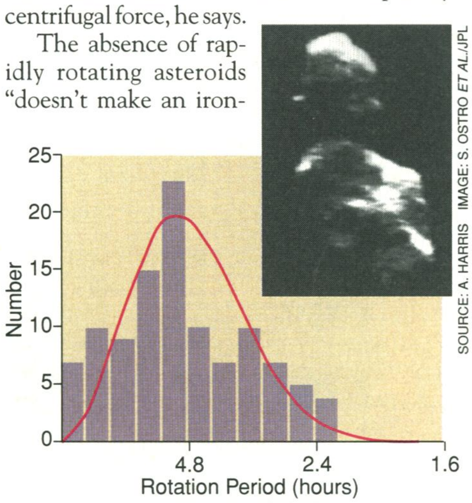
Asteroids lead a hard life, punctuated by collisions. That has led many planetary scientists to wonder whether, instead of being solid chunks of rock, asteroids are simply jumbles of rocks held together by their own gravity. The close-up views of the asteroids Gaspra and Ida sent back by the Galileo spacecraft when it passed by in 1991 and 1993 didn't settle the issue, because the asteroid surfaces were covered with debris that hid any inner structure. But at last month's Lunar and Planetary Science Conference in Houston, astronomer Alan Harris of the Jet Propulsion Laboratory in Pasadena, California, presented the strongest evidence yet that most asteroids are simply piles of rubble.

Harris's case, which researchers call intriguing if not compelling, is based on the absence of rapidly rotating small asteroids, which suggests that only gravity, not the strength of solid rock, is holding asteroids together against centrifugal force. If his findings hold up, they could shed light on asteroid evolution and behavior. But the results could also mean that it might be harder to protect Earth from an asteroid on a collision course.

Because of their small size, asteroids appear simply as points of light to ground-based telescopes. But astronomers can detect pulsations in the brightness of the sunlight reflected off irregularly shaped asteroids as they rotate. From the repetition rate of the brightness variations, they infer the length of an asteroid "day."

Using the 24-inch telescope at Table Mountain Observatory in California, Harris and his colleague James Young logged the rotation periods of about a dozen asteroids, to which Harris added results from other astronomers to get rotation data on a total of 107 asteroids ranging in size from 200 meters to 10 kilometers. These small asteroids tend to rotate faster than their bigger siblings—the average period is 5 hours—which should make them a more sensitive test of asteroid strength. And Harris found that none of his asteroids has a period of less than 2.3 hours, a cutoff that makes sense, Harris calculated, if asteroids are rubble piles held together only by gravity. Any rubble pile rotating at a speed faster than this cutoff would be torn apart by centrifugal force, he says.

The absence of rapidly rotating asteroids "doesn't make an iron-clad case," says Harris, "but it looks from this work that most asteroids 1 to 10 kilometers in diameter are rubble piles." William Bottke of the California Institute of Technology (Caltech) agrees. At the Houston conference, he and Jay Melosh of the University of Arizona argued that rubble-pile asteroids could explain close pairs of craters common on the planets. A rubble pile, they said, could be torn into two smaller bodies orbiting each other if it passed close to Earth; if it hit Earth the next time around, it would create a crater pair. "It all points in the direction of a lot of asteroids being rubble piles," says Bottke.



Limits to spin. A lack of rapid rotators suggests asteroids are composed of multiple blocks, as a radar view of Toutatis implies.

While piles of rubble in space may seem less threatening than huge solid rocks, they would wreak as much havoc if they hit Earth, and they could be harder to fend off. Researchers looking for applications for technology developed during the Strategic Defense Initiative in the 1980s have proposed shattering and dispersing an oncoming asteroid with nuclear bombs or other devices (*Science*, 16 June 1995, p. 1562). But in Houston, Thomas Ahrens of Caltech said a computer model of rubble-pile collisions he developed with colleague Stanley Love predicted that "it's just a heck of a lot harder to break up a bag of sand than a rock."

Still, it may be too early for the Star Warriors to start worrying. Planetary scientist Joseph Veverka of Cornell University is among those who want more evidence. "Are most asteroids rubble piles," he asks, "or just some? We don't know that yet." The rubble-pile picture will get a big test when NASA's recently launched Near-Earth Asteroid Rendezvous (NEAR) spacecraft orbits the asteroid Eros in 1999. The rate at which NEAR orbits Eros will reveal whether Eros is a solid, high-density rock or a low-density mix of rubble and fine debris. Harris already has his money down: "I would predict Eros is a rubble pile."

–Richard A. Kerr