# Materials Science

*Ivan Amato reports from San Francisco at a meeting of the Materials Research Society*

## Cutting curves in Samurai swords

The graceful and fearsome swords of Samurai warriors embody metallurgical genius. Even as far back as the 8th century, Japanese swordsmiths were transforming straight steel strips into lightweight weapons with an unprecedented hardness and toughness that helped elevate the Samurai to legendary status.

Researchers have known for years that these swordsmiths forged two types of steel into blades with interiors, sides and edges respectively containing increasing amounts of carbon, most often picked up from charcoal burning in the forge. Although the high-carbon steel in the edges accounts for some of the swords' superior qualities, research metallurgist William N. Weins of the University of Nebraska in Lincoln suggests that the method of quenching, or cooling, the metal played an equally important role in toughening the edge while automatically producing the blade's graceful arch.

The swordmakers surrounded all but the cutting edge of a partly worked blade with clay. This allowed a heated edge to heat and cool faster than other parts of the blade. During quenching, the crystalline structure of steel undergoes a transformation that results in expansion. For example, Weins calculates that the exposed edge of an otherwise clay-encased blade spanning 3 feet would expand ¾ of an inch more than the blade's slower-cooling back. Not only could this differential expansion account for the famous sweeping curve of Samurai swords, but it would also leave the finished edge under huge, permanent compressive forces.

"The atoms in the edges are always being pushed together," Weins says. His measurements of strain in sections of 16th- and 17th-century Samurai swords support this picture. Without the compression, the edges would still have become extremely hard but would be so brittle and ridden with microcracks that the blades "would have snapped just like a piece of glass the first time anyone tried to use them," Weins surmises.

## A woody path to biodegradable plastics

For thousands of years, people have used vast amounts of wood for such low-tech applications as building their homes and fueling their fires. But wood scientists, who think of wood as "three-dimensional biopolymer composites," want to see this age-old, renewable and biodegradable resource become the fount of high-tech materials, including plastics.

The U.S. pulping industry produces 20 million tons of lignin — the complicated biopolymer that makes trees woody — as a by-product of paper making, says wood scientist Simo Sarkanen of the University of Minnesota in St. Paul. Virtually all of this lignin — the second most abundant biological polymer on Earth — gets burned as waste.

Sarkanen suggests that the huge, renewable stores of lignin could become feedstock for a wide range of biodegradable polymers. Lignin's complicated and only partially understood chemical structure — involving up to three types of molecular units that can link in as many as 10 ways — so far has discouraged researchers from developing lignin into a routine chemical basis for polymers and other higher-tech materials.

Although the chemical complexity of lignin in trees may be hopelessly daunting, the lignin that emerges from the pulping process appears to follow some structural rules, Sarkanen reports. For example, he and his colleague Sunil Dutta find that lignin components of specific molecular sizes link and dissociate in particular orders. Without disclosing details, Sarkanen says that he and co-workers already are using these rules to develop methods for casting films made of the lignin biopolymer. Since such polymers are nothing more than transformed wood, natural wood-eating microorganisms would make discarded lignin-based plastics disappear, he says.

# Physics

*Ivars Peterson reports from Washington, D.C., at a meeting of the American Physical Society*

## Gamma rays from the Crab nebula

The Crab nebula, the optical remnant of a stellar explosion observed more than 900 years ago, is already known as one of the strongest sources of X-rays and radio waves. Now a team of astronomers has established that the Crab nebula is also a steady source of highly energetic gamma rays. "We have seen a very clear signal from the Crab nebula," says Trevor C. Weekes of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. "It's a completely steady source of gamma rays."

The energy source powering the Crab nebula is most likely a rotating neutron star, which has a high magnetic field and can accelerate electrons to relativistic energies. These accelerated electrons interact with low-energy photons in the region surrounding the neutron star to generate gamma rays. The resulting gamma rays typically have energies exceeding those achievable in any particle accelerator or collider on Earth.

The steadiness of the signal establishes the Crab nebula as a standard against which to measure other gamma-ray emissions. A number of research teams have previously detected high-energy gamma rays from cosmic sources, but nearly all these signals proved sporadic and unpredictable. The existence of a single, well-understood source of cosmic gamma rays may help astronomers interpret other, more puzzling gamma-ray observations.

"The Crab is a weak gamma-ray source, but it's the strongest source yet detected," Weekes says. "It provides a standard signal."

## Putting limits on the top quark

Particle physicists have so far found evidence in the debris from particle collisions for five species of quarks: up, down, strange, charm and bottom. But the so-called standard model of particle physics predicts a sixth species: the top quark. Researchers working with a detector at the Fermi National Accelerator Laboratory's Tevatron collider in Batavia, Ill., now conclude that the top quark, if it exists, most likely has a mass greater than 89 billion electron-volts (GeV) but less than 250 GeV. They see no trace of the telltale signals that would reveal the production of a top quark in any of 200 billion collisions between protons and their antimatter counterparts during last year's Tevatron experiment.

Physicists are puzzled by why the top quark should have such a large mass. At roughly 0.4 GeV, the up and down quarks, from which one can build protons and neutrons, are relatively light. The proton mass itself is a little less than 1 GeV. The strange quark has a mass of about 0.5 GeV, the charm quark about 1.5 GeV and the bottom quark about 4.5 GeV. The apparent trend of heavier quarks being three times more massive than their predecessors suggests that the top quark ought to have a mass around 13.5 GeV. But every search so far has found no top quark, pushing its expected mass ever higher.

If the top quark has a mass of 130 GeV or less, then researchers at Fermilab may yet catch a glimpse of this elusive beast. "This puts the top quark within the reach of the Tevatron if proposed upgrades are implemented," says Fermilab's Hans B. Jensen.

## And then there were three

By observing the many ways in which a particle known as the $Z^\circ$ can decay into other particles, researchers working with the ALEPH detector at the Large Electron-Positron collider in Geneva, Switzerland, have now obtained the most stringent limit yet excluding the existence of a fourth generation of elementary particles. Their results firmly establish that the elementary particles of matter fall into only three sets, each one characterized by a particular type of neutrino (SN: 10/21/89, p.260).