A Metallurgical Tale of Irony

Two Stanford investigators studying superplastic metals rediscover the secret of manufacturing Damascus steel

While researching for new ways to process metals into complicated shapes, two investigators have inadvertently rediscovered the secret of manufacturing the legendary Damascus steel. Oleg D. Sherby of Stanford University and Jeffrey Wadsworth, who is now at the Lockheed Palo Alto Research Laboratory, have produced "the first modern recipe" for making swords of Damascus steel and, in the process, have unraveled much of the mystery that has long surrounded the superb blades.

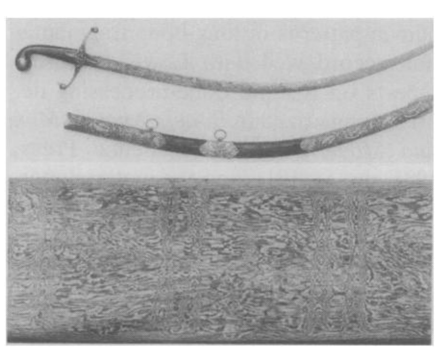
Swords of Damascus steel dominated warfare for centuries because of their exceptional toughness and their uncontested retention of a cutting edge. It has been claimed that Alexander the Great carried weapons of Damascus steel as long ago as 320 B.C. It is certain that they were well known from the beginning of the Islamic period, about A.D. 620, until well after the Middle Ages. The name derived from the fact that Europeans first encountered this steel in Damascus, but the metal itself was actually produced in India. Cakes of the metal, called *wootz*, were then shipped to Russia and the Middle East for forging into weapons. Swords and other implements made from the *wootz* were characterized by their unique surface markings, which could not be reproduced elsewhere.

The puzzle of the metal arose not only from its superiority to other metals but also from the inability of European forgers to duplicate it—or even to work with it. When European metalworkers tried to work the *wootz*, it would crumble. Because the "barbarians" could do something they could not, Europeans built a layer of mystique around the metal.

Europeans of the 18th and 19th centuries struggled mightily to recreate the legend. Michael Faraday, the blacksmith's son of electrochemistry fame, failed to reproduce Damascus steel, but almost invented stainless steel; he incorrectly attributed the properties of *wootz* to small amounts of silica and alumina. Jean Robert Breant, Inspector of Assays at the Paris Mint, tried adding gold, platinum, silver, uranium, arsenic, and other elements in some 300 experiments during a frantic 6 weeks, but did not make Damascus steel. He did conclude, however, that the important feature of Damascus steel was a high carbon content, between 1 and 2 percent. A Russian, P. Anossoff, tried adding diamonds to steel: right element—wrong process. Interest in Damascus steel eventually waned as firearms assumed greater importance. One or two investigators have produced metals very similar to Damascus steel, says Wadsworth, but their work "involved a lot of gut feeling without any real precision."

The keys to production of Damascus steel are the carbon content and the nature of the heat treatment, Wadsworth told a meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers in Louisville in October. Because the steel had a high carbon content, it had to be worked at a much lower temperature than European forgers were used to. The ideal temperature for *wootz* to be worked is between 700° and 900°C, but European ovens operated at around 1300°C, at which temperature their low-carbon steel was most malleable. At 1300°C, however, high-carbon *wootz* is partially solid and partially liquid, so that it shatters when struck.

All metals are composed of grains. The carbon in the *wootz* would initially form a network of coarse particles along the edges of the grains; these particles were relatively large and weakened the structure of the steel. Repeated working of the steel at warm temperatures breaks up these coarse particles and makes the steel much stronger, Wadsworth and Sherby explain. It is the final distribution of fine iron carbide particles, they add, that produces the characteristic surface markings of Damascus steel, a fact only imperfectly recognized previously. One of their primary achievements, Wadsworth says, is to quantify precisely the range of particle sizes required and the temperatures needed for processing.



Mohammed's Ladder

A sword and scabbard of Damascus steel and a macrograph of the sword's surface. This pattern is known as Mohammed's Ladder *because of the repeated vertical markings. [Metropolitan Museum of Art, bequest of George C. Stone, 1936]*

Cooling the blade after it was worked was also important. Some Persian texts insisted that the red-hot blade should be quenched by plunging it into the belly of a muscular Nubian slave. Other texts suggest quenching in the urine of a red-haired boy or of goats that had eaten nothing but ferns for 3 days. Sherby and Wadsworth have also provided precise instructions for quenching and tempering Damascus steel.

The two investigators were seeking a way to produce ultrahigh-carbon steels without the granular particles. Such steels are superformable or superplastic (that is, easily molded into complex shapes) at warm temperatures while retaining strength and toughness at room temperatures. They were not aware of the connection between their work and Damascus steel until a colleague pointed it out to them. They have since made extensive literature surveys and studies on the metal on their own time and with their own resources.

Superplastic metals have many potential applications where complicated metal shapes must be produced with a minimum of machining. Their use can lead to large weight and cost savings. One good potential application of Sherby and Wadsworth's materials would be bevel gears for automobile transmissions. Parts of turbines in military jet engines produced by Pratt & Whitney are already made of a nickel-based superplastic alloy. The nacelles holding the engines on the wings of the B-1 bomber are also made of a titanium superplastic alloy.

The best materials produced by Sherby and Wadsworth have a much finer grain structure than that of Damascus steel and thus do not have the characteristic surface markings. They are also much stronger. But the two investigators conclude that Damascus steels could have been made by their route and that these may have been among the best produced.—THOMAS H. MAUGH II

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