Wires: From Chainmail to Superconductors

With all the recent excitement about oxide-ceramic superconductors, materials researchers still face the major challenge of how to form these materials into wire. Earlier low-temperature superconducting wires, cooled by liquid helium, were used for giant superconducting magnets and other applications, but the new oxide-ceramic materials offer the possibility of relatively inexpensive applications, from virtually free electricity distribution to levitating trains and to smaller microchips. Unfortunately, most of these experimental superconductors are brittle and fragile, which makes them impossible to draw into wire. A team of scientists at AT&T Bell Laboratories has recently produced a prototype superconducting wire by filling a hollow metal wire with powdered superconducting material. Other researchers at Argonne National Laboratory have created a thin wire of their superconducting material and are working to improve its current density.

Of course, wire and its properties are nothing new. Recorded uses of wire go all the way back to the Bible. Archaeological discoveries have shown that wire was made in ancient China and the Middle East, in the tombs of the pharaohs in Egypt, and in the buried ruins of Pompeii. Such early wire was made by hammering and beating thin strips of metal. The most ductile metals include copper, gold, silver, zinc, aluminum, and brass.

As described in an English list from 1565, the historical uses of wire range from ornamental to functional—"knitting needles, nayles, pack-needles, chaynes, burde caiges, mouse trappes, buckles, iron rings, and like iron wyre wares." In the Middle Ages, wire was even used for making the rivets and flexible parts of suits of armor.

The process of drawing wire by pulling metal—by hand—through a die was in use as early as 1000 A.D. The wire-puller would hammer a section of metal to be drawn into a point, which he then pushed through a hole in the die. The shape of the finished wire depended on the shape of the die-hole through which it was pulled. The earliest wire-pullers used dies made of either iron or stone with holes drilled through them.

Workers could pull only short lengths of wire at a time, and only with extreme effort. Using his own strength, the wire-puller grasped the point with tongs and pulled the metal through the hole, drawing a strand of wire. Presumably, the metal was heated before this operation, though some accounts say wire-pullers grasped the point with their bare hands. It is obvious that no large-diameter wire could be drawn this way unless the metal was very soft; as an alternative, large-diameter wire could be fashioned by hammering or rolling metal rods. Some creative inventors developed such contraptions as hanging chairs and foot braces to allow them to pull with their arms while pushing with their feet. With each pull, a worker could draw a length of wire nearly equal to his own height, then grasp the end of the wire near the die and pull again.

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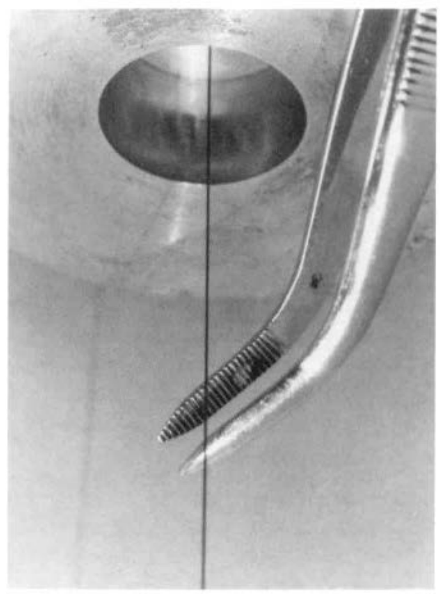
In 1350, Rudolf of Nurenberg developed a water-powered method of wire-drawing, which the Germans kept a close secret for the next century and a half until Eobanus Hessus wrote about the water-powered process. "One can see how the work is done by the weight of wheels and with what great power they can stretch the iron and how they perform what a thousand men could not do before the art was discovered.... The tongs seize with their sharp teeth the raw iron, smooth it into round wire, which is taken out of the tongs and coiled into a thousand convolutions." By 1565, water-powered wire mills had appeared in England, and in the United States by 1650. The steam engine, in 1769, practically eliminated manual wire pulling.

A strand of wire can be reduced in diameter only by a certain percentage, depending on the original metal's physical characteristics such as its ductility and tensile strength. To manufacture very fine wire, the strands must travel through successive dies, reducing the diameter at each pass. Modern wire-drawing machinery can reduce the diameter of the metal about 25% for each pass through a die. As the wire passes through the drawing process, the grains of metal are severely deformed, leaving the wire under great internal stress or "work hardened." A wire drawn beyond the work-hardening limit will become brittle and break. At this point, the wire must be softened, or annealed, which allows the metal grains to resume their original shapes.



In March 1987, researchers at Argonne National Laboratory became the first Americans to form a high temperature superconductor into the shape of a wire. Argonne National Laboratory photo.

In 1862 the Homestead Act opened the American frontier to settlement, creating an enormous demand for fencing wire. At first it was customary to use round or oval wire, or flat wire with serrated edges—these did not prove acceptable, though. When cattle ran into or leaned against such fences, the wire broke easily. Also, the fence wire could not withstand the expansion and contraction brought about by weather shifts. Barbed wire was patented in 1867, consisting of two strands of twisted wire—to permit expansion and contraction without breakage—and sharp barbs—to discourage cattle from pushing against the fence.

About the same time, the demand for wire rope, or cable, increased. This was used for hoisting, construction, suspension bridges, and even oil-well drilling. The first wire ropes were made by tying together individual strands of wire into a cable of the desired thickness. Unfortunately, the tie wires themselves slipped, and the single strands of wire varied too much in quality. Until the development of the open-hearth and the Bessemer processes for steelmaking, industry could not create suitably uniform steel in the long lengths required for good, flexible wire ropes.

During the 19th Century, several major technological and social changes brought about an enormous demand for high-quality wire. The telegraph was invented by Samuel F.B. Morse in 1835; the first line laid between Baltimore and Washington in 1844 was only the first of many long wires connecting the entire country. Similarly, when Alexander Graham Bell invented the telephone in 1870 and when Thomas Edison invented the electric light in 1880, both systems required great quantities of wire.

The 20th Century German development of tungsten carbide dies allowed fast and precise drawing of wire. Tungsten carbide is very hard and holds an exact shape through which the wire can be drawn. Tungsten carbide, however, is very brittle and a steel case must be used to reinforce the carbide nib. Other dies are made from tantalum carbide, hard chrome steels, and chilled iron. For very fine wire, less than 0.03 cm in diameter, diamond dies may be used.

Because of the heat generated by the wire-drawing process, dies are usually cooled with water. The feed rods of metal are also lubricated, since the heat could cause the metals to seize while they are being drawn through the die, or the friction would either scratch the wire or ruin the die itself. These lubricants have been specially developed for certain types of wire and often contain additives such as metallic stearates for copper and aluminum, or the highly heat-resisting materials graphite or molybdenum disulfide for metals that must be heated before drawing.

Wire is commonly used for wire ropes and cables, fences, chains, ornamentation, nuts, bolts, rivets, needles and nails, trays and baskets, and electrical wire. But the advent of experimental superconducting materials, brittle oxide ceramics, adds a completely new twist to the manufacture of wire which demands much more than the old wire-drawing methods can provide.

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