The Basics of Wire

Wire: a Primer

One can work in the mire and cable industry for years without knowing much about its origins. To that end, me offer this primer by Dr. Robert Shemenski, RMS Consulting, Inc., a past Wire Association International president who has also served as the association's technical contractor.

Also included in this section is information on the nonferrous sector from Dr. Horace Pops, Superior Essex, and the fiber optics sector from Stephen Montgomery, ElectroniCast Corp., and Dr. Paul Polishuk, Information Gatekeepers, Inc.

A definition and brief history of wire

Wire

1) A thin, flexible, continuous length of metal, usually circular in cross-section, and typically manufactured by drawing through a die, rolling, or swaging. Wires are classified as ferrous (iron, carbon steel, stainless steel) or nonferrous (copper, brass, bronze, zinc, aluminum, nickel, gold, silver, platinum, tungsten). Certain specific metal alloys may be cast directly from molten metal into rotating water giving the desired circular shape of wire.

2) A continuous length of solid metallic electrical conductor. Several individual conductors may be twisted together by stranding or bunching to form cables.

3) A roughly geometric mill product, usually rectangular, square, oval, or triangular but narrower than strip, in which all surfaces are rolled or drawn through shaped dies without any previous slitting, shearing, or sawing. Such wire is often called “flat” or “shaped” wire.

Wire manufacturing

The history of wire making (drawing) starts about 5000 BC or earlier. Exodus (39:3), the second book of the Old Testament that dates back to 1500 BC, refers to an ancient craft called wire making. However, archaeological discoveries date the art of wire making even earlier. A necklace consisting of oval gold plates connected by a crude chain of gold wires was found belonging to an Egyptian Pharaoh who reigned about 2750 BC. Assyrians and Babylonians made wire at least as early as 1700 BC, probably for jewelry and ornaments.

Utilitarian uses of wire soon followed. A piece of wire rope made in Nineveh about 800 BC is on exhibit in the British Museum. It consists of parallel wires bound with bands of wrought metal similar in construction to modem suspension bridge cables. Three bronze vires twisted together to form a cable were found in ruins of Pompeii. For many centuries, wire vas manufactured by hammering a ductile metal, such as gold or bronze, into thin sheets and then cutting these sheets into narrow strips. Hammers and files were used to fabricate strips into short, round pieces. These small lengths were then hammered or brazed together to form longer wires.

Drawing wire also goes well back into antiquity. Wire used for wire rope in Pompeii around 500 BC was made by drawing metal through a tapered hole in a die. Historians are confident that Egyptian artisans drew gold tubes through tapered holes of decreasing size punched into bronze plates. Archaeologists found perforated stones that were used as dies for drawing wire. Iron artifacts identified as wiredrawing dies dating back to 300 AD were found in Central France and dies were found in Viking graves from about 700 AD. The first technical reference to an iron die plate was published in Latin about this time by the monk Theophilus, who wrote, “Two pieces of iron three or four fingers wide, smaller at the top and bottom, rather thin, pierced with three or four holes through which wire is drawn.”

Manufacturing wire by drawing through dies became common after about 1000 AD, and by the 13th and14th centuries, wire drawers were well established in France and England. In the middle ages, wire was drawn by hand. For example, in Germany an artisan grasped the wire to be drawn with tongs fastened to his belt. A die, or draw plate, was anchored to a tree stump or block of wood. Seated on a swing, the wire drawer swung forward, gripped the wire at a point near the hole in the die with his tongs, and shoved away from the draw plate. About one foot of wire was drawn for each swing of the wire drawer. If finer wire was needed, the wire vas pulled through successively smaller dies until it was the proper size, and then wound on a spool or reel. This process for drawing wire was used in parts of Russia and Sweden as late as the mid- 18th century.

Waterpower replaced hand power to draw wire in Germany around 1350, although both water driven and hand operations continued well into the 19th century. About 1650, artisans near Düsseldorf discovered the advantage of using lubricants to draw hard steel. Prior to that, only wrought iron could be drawn into wire. Urine and stale beer were used for these early drawing lubricants. The wire industry was established in the United States during the Revolutionary War when wire was no longer available from England. By 1834 there were only three wire mills in the U.S., and their combined production was around 15 tons per year.

The basic method of wire manufacturing, *viz*., drawing a soft, ductile metal through a hard, incompressible die, has remained unchanged for centuries. Modern wiredrawing technology permits greater quantity and quality to be produced today in a wiredrawing mill. Manufacture of wire starts with molten metal. Up to the mid-20th century, molten steel from a basic oxygen furnace or an open-hearth furnace was cast into ingots. These ingots were cut into blooms, homogenized in a soaking furnace and rolled in a blooming mill into billets. During the last half of the 20th century with the evolution of electric arc furnaces, continuous casting of molten ferrous metals into billets was developed. This technology was more energy-efficient and economical.

In a ferrous rolling mill, billets are heated in a soaking furnace to ensure uniform chemical composition throughout the billet for production of steel wire. The homogenized billets are hot-rolled through roughing and finishing stands to the desired wire rod size. The hot-rolled wire is formed into coils and control-cooled on a Stelmor deck to develop the correct microstructure, mechanical properties and oxide formation.

Coils of wire rod are taken to the wire mill where the rod is drawn into wire. The first wire mill process is to remove any iron oxide scale from hot rolling and rust that formed on the rod during storage and transportation. Steel rod is prepared for wiredrawing in two ways. In one process, rod is immersed in either hydrochloric acid or sulfuric acid to remove the scale, rinsed in water, coated with phosphate, lime, or borax, to neutralize residual acid, to provide corrosion temporary protection, and to serve as a lubricant carrier in the subsequent wiredrawing operations, and then dried. An alternate process for scale removal is by using a mechanical descaler, which involves reverse bending the rod by flexing the rod over sheaves to break loose and to remove the high temperature scale. Metallic grit blasting and high-pressure water also have been used to clean wire. The mechanically descaled rod is then coated with lubricant carrier prior to wiredrawing.

Nonferrous electrical conductors became of age in the late 1800s with the dawn of the telegraph and telephone. Prior to that time, iron wire had been used in the telegraph system. For about the first half of the 20th century, the traditional way of producing copper rod was the same as it had been before the turn of the century, namely, it was a batch operation. Refined molten copper was cast horizontality into individual 113 kg wire bars having tapered ends for easy entry into rolling mills.

Continuous casting and tandem hot roiling into rod soon evolved, and rapidly expanded globally throughout the entire wire and cable industry. The first continuous endless mold was formed between a rotating wheel having a groove in the outer periphery and a flexible steel band. Although this method of casting was developed in 1882, however, it was not commercialized until 1948 when it was used successfully to produce lead, aluminum, and zinc. This type of process is now used extensively for the manufacture of many different nonferrous metals and alloys. Since that time several other horizontal and vertical continuous casting methods have evolved, as for example, the twin belt system. Because of the heavy oxide scale that forms on the surface of bot as-cast copper bars, several different cleaning methods have been adopted for the continuous casting process. These inline methods include either mechanical descaling using high pressure sprays of the mill solution, pickling with a sulfuric acid solution, or chemical reduction of the scale to its metal by immersing the hot rod into an aqueous solution containing an organic addition, as for example, alcohol.

A sharp point or gradually reduced cross section is formed on the leading end of coated or lubricated rod to permit threading the rod into a series of tapered, conical dies. The lubricated rod is pulled through a series of dies reducing its diameter and increasing its length. Wiredrawing may be done one die at a time in a single-hole drawing machine or through several dies sequentially by using a multi-hole wiredrawing machine. For steel wire, drawing dies are made from tungsten carbide, whereas synthetic or natural diamond dies are now used almost exclusively for nonferrous wire such as copper and aluminum. Carbide dies were introduced in the US. wire industry in 1928, one year before the Wire Association was organized.

Wire tends to “work-harden” during drawing so that it may have to be softened between drawing steps by heat treatment. This heat-treatment is called ‘‘patenting’’ for ferrous wire and “annealing” for nonferrous wire.

Classification of round wire

Standard nominal diameters and cross-sectional areas of solid, round copper wires used as electrical conductors are prescribed in ASTM B258. American Wire Gauge (AWG) is a US standard for nonferrous (e.g., copper and aluminum) wire conductor sizes. The “gauge” means the wire diameter. See Table I. AWG is also known as Brown & Sharpe (BS) wire gauge. The AWG system is based on fixed diameters for two wire sizes (4/0 and 36 AWG, respectively) with a geometric progression of wire diameters for the 38 intermediate gauges and for gauges smaller than 36 AWG. A 0000 (4/0) AWG wire is defined as 460 mils (0.460 in., 11.68 mm) in diameter and 36 AWG wire is 5 mils (0.005 in., 0.127 mm) in diameter. AWG is an inverse series designation scheme in which a higher number denotes a smaller wire diameter. Typical household copper wiring is AWG number 12 or 14. Telephone wire is usually in the size range 19 to 26 AWG.

Each increase in one AWG number is approximately equivalent to a 20.7 percent reduction in cross-sectional area (ROA) for nonferrous wires. For ferrous wire, reduction in cross-sectional area is not constant for an increase in AWG number as shown in Table II. A reduction in diameter for a ferrous wire from AWG I to AWG 2 results in a 13.96 percent ROA, whereas, a decrease in diameter from AWG 9 to AWG 10 results in a 17.13 percent ROA.

Table I: AWG Sizes (Nonferrous)

AWG	DIA (IN)	DIA (MM)	AREA (IN²)	ROA
1	0.283	7.188	0.062902	0
2	0.263	6.668	0.054119	13.96%
3	0.239	6.190	0.046645	13.81%
4	0.225	5.723	0.039867	14.53%
5	0.207	5.258	0.033654	15.58%
6	0.192	4.877	0.028953	13.97%
7	0.177	4.496	0.024606	15.01%
8	0.162	4.116	0.020612	16.23%
9	0.148	3.767	0.017273	16.20%
10	0.135	3.429	0.014314	17.13%
15	0.072	1.829	0.004072	71.55%
20	0.035	0.884	0.000951	76.65%
30	0.014	0.356	0.000154	83.81%
40	0.007	0.178	0.000038	75.32%

Table II: AWG Sizes (Ferrous)

AWG	DIA (IN)	DIA (MM)	AREA (IN^2)	ROA
1	0.2893	7.3482	0.064733652	0
2	0.2576	6.5430	0.052117385	20.71%
3	0.2294	5.8268	0.041331172	20.71%
4	0.2043	5.1892	0.03278141	20.69%
5	0.1819	4.6203	0.025987009	20.73%
6	0.1620	4.1148	0.020612038	20.68%
7	0.1443	3.6652	0.016353984	20.66%
8	0.1285	3.2639	0.012968721	20.70%
9	0.1144	2.9058	0.010278813	20.74%
10	0.1019	2.5883	0.008155287	20.66%
15	0.0571	1.4503	0.002560726	68.60%
20	0.0320	0.8118	0.00080224	68.67%
30	0.0100	0.2545	7.88545E-05	90.17%
40	0.0031	0.0798	7.74373E-06	90.18%

In Europe, wire diameters are specified by using the imperial Standard Wire Gauge (ISWG) system. Table III shows the conversion from AWG to ISWG.

Table III: American Wire Gauge to Imperial Standard Wire Gauge

AWG	AWG DIA (IN)	AWG DIA (MM)	ISWG DIA (IN)	ISWG DIA (MM)
0000 (4/0)	0.4600	11.6840	0.4000	10.160
000 (3/0)	0.4096	10.4038	0.3720	9.4488
00 (2/0)	0.3648	9.2659	0.3480	8.8392
0 (1/0)	0.3249	8.2525	0.3240	8.2296
1	0.2893	7.3482	0.3000	7.6200
2	0.2576	6.5430	0.2760	7.0104
3	0.2294	5.8268	0.2520	6.4008
4	0.2043	5.1892	0.2320	5.8928
5	0.1819	4.6203	0.2120	5.3848
6	0.1620	4.1148	0.1920	4.8768
7	0.1443	3.6652	0.1760	4.4704
8	0.1285	3.2639	0.1600	4.0640
9	0.1144	2.9058	0.1440	3.6576

AWG	AWG DIA (IN)	AWG DIA (MM)	ISWG DIA (IN)	ISWG DIA (MM)
10	0.1019	2.5883	0.1280	3.2512
15	0.0571	1.4503	0.0720	1.8288
20	0.0320	0.8118	0.0360	0.9144
30	0.0100	0.2545	0.0124	0.3150
40	0.0031	0.0798	0.0048	0.1219

Wire use

Nonferrous metals, usually commercial purity copper and aluminum are used in the annealed condition for telephone and electrical wiring since these metals are very ductile and good conductors of electricity. Very thin platinum wires are used for telescopes and for electrodes in electrochemical instruments due to their resistance to oxidation. Gold and silver wires are used for jewelry and ornaments. Tungsten wire is used for filaments in light bulbs. Copper wire is often coated with a non-conducting organic outer covering and used to convert electrical energy into work for such applications as generators and motors. This type of composite material is referred to as winding wire or magnet wire. More than half of the copper consumed today is used to produce electrical conductor wire.

Ferrous wire, usually carbon steel and stainless steel, has many industrial uses because of its higher strength, for example, fasteners (nails, nuts, bolts, staples, paper clips, screws) and musical instruments (guitar and violin strings). Steel wire is also used for fencing materials, springs, screens, woven mesh and reinforcement (tire cord, pre-stressed concrete strand, automotive bead wire). Steel wire rope is made by twisting individual wires into cables that are used to support suspension bridges and for cables in construction equipment and oil and mining operations.

Fiber optics

Fiber optic fiber, which provides light transmission through optical fibers for communication or signaling, has grown into a major medium since it first became commercially viable in the mid- to late-1970s. It is drawn from a preform of highly purified and/or doped glass and made into a single, separate optical transmission element, characterized by a core and a cladding, There are two basic modes (light paths) for optical fibers: single-mode and multi-mode. The glass-fiber core of a multimode fiber is typically 62.5 microns in diameter; a single-mode core ranges from 8 to 11 microns.

Both fiber types are surrounded by a cladding that increases the diameter to 125 microns, and a coating that extends the diameter farther to 250 microns. Multimode fiber allows the light to follow multiple (different) paths, or “modes,” when the optical signal is traveling down its length.

It can be either step index or graded index to increase the bandwidth of the fiber. The optical core of the single-mode fiber is smaller than the multimode, thus allowing only a single light path, or “mode” for the optical signal traveling down the length of the fiber.

The transmission capacity of optical fiber is truly stunning. In its early days, state-of-the-art transmission was considered 45 megabits (the equivalent of 700 voice channels). As of early 2003, that same measure is now 40 gigabits (the equivalent of 625,000 voice channels), and further work is being done that may in fact dwarf even those latter figures.

The industry

Wire has been produced and in demand for the past 7000 years. The range of products and the technology and methods to produce them have evolved greatly and undoubtedly will continue to do so. Yet there is a constant that should not be overlooked: the wire and cable industry continues to serve a vital role in the everyday fabric of life. From communications to infrastructure, wire and cable is an essential — albeit low-profile — part of the total “big picture”. It is a field in which those who work should be proud.