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Wire Ropes, Elements and Definitions

1.1 Steel Wire

The very high strength of the rope wires enables wire ropes to support large tensile forces and to run over sheaves with relative small diameters. Very high-strength steel wires had already been existence for more than a hundred years when patenting – a special heating process – was introduced and the drawing process perfected. Since then further improvements have only occurred in relatively small steps.

There are a number of books about the history of wire ropes and wire rope production beginning with its invention by Oberbergrat Wilhelm August Julius Albert in 1834 and one of these is by Benoit (1935). Newer interesting contributions on the history of wire ropes have been written by Verreet (1988) and Sayenga (1997, 2003).

A voluminous literature exists dealing with the manufacture, material and properties of rope wires. In the following, only the important facts will be presented, especially those that are important for using the wires in wire ropes.

1.1.1 Non-Alloy Steel

Steel wires for wire ropes are normally made of high-strength non-alloy carbon steel. The steel rods from which the wires are drawn or cold-rolled are listed in Table 1.1 as an excerpt of a great number of different steels from the European Standard EN 10016-2. The rods for rope wires have a high carbon content of 0.4–0.95%.

The number in the name of the steel gives the mean content of carbon in weight percent multiplied with the factor 100. For example, the steel name C 82 D means that the steel has a mean carbon content of 0.82%. Steels with high carbon content close to 0.86% with eutectoid fine perlite – a mix of cementite (Fe_3C) and ferrite – are preferred for rope wires.

Table 1.1. Non-alloy steel rod for drawing (excerpt of EN 10 016-2)

Steel name	steel number	Heat analysis carbon content (%)
C 42 D	1.0541	0.40–0.45
C 48 D	1.0517	0.45–0.50
C 50 D	1.0586	0.48–0.53
....	....	....
....	....	....
C 82 D	1.0626	0.80–0.85
C 86 D	1.0616	0.83–0.88
C 88 D	1.0628	0.85–0.90
C 92 D	1.0618	0.90–0.95

Carbon steels only contain small quantities of other elements. EN 10016-2 gives the following limits for the chemical ingredients of carbon steel rods used for rope wires: Si 0.1–0.3%, Mn 0.5–0.8%, P and S <0.035%, Cr <0.15%, Ni <0.20%, Mo <0.05%, Cu <0.25% and Al <0.01%. The strength increases with an increasing carbon content and the breaking extension decreases if all other influences are constant. Higher contents of sulphur S, phosphorus P, chrome Cr and copper Cu reduce the steel's ductility, Schneider (1973).

Usually, wires for wire ropes have a round cross-section. In special cases, however, wires with other cross-sections – called profile wires – are used. The different cross-sections are to be seen in Fig. 1.1. The profile wires in the upper row are inserted in locked coil ropes. The wires below are used for triangular and oval strands.

In wires with a high carbon content which had been aged artificially, Unterberg (1967) and Apel and Nünninghoff (1983) found a distinct decrease in the breaking extension and the number of turns from the torsion test. The

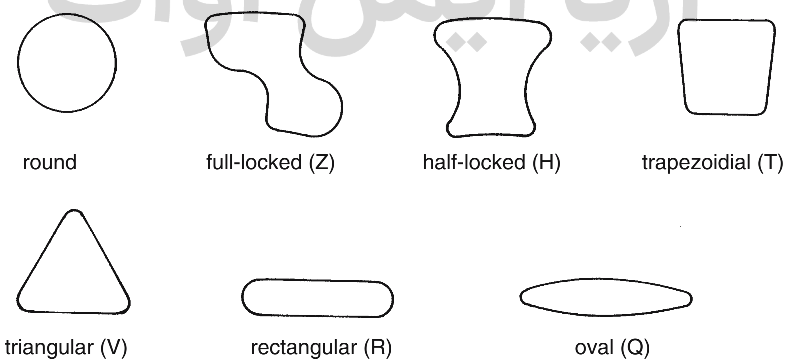

Fig. 1.1. Wire cross-sections for wire ropes

number of test bendings is slightly reduced and the strength slightly increased. The finite life fatigue strength is partly increased or decreased.

Bending tests were repeated with three wire ropes after they had been in storage for 22 years. The original tests were well documented and the new tests were done in the same way with the usual lubrication. There was virtually no difference in the rope bending endurance documented for the original tests and the new tests. For two of these wire ropes, the mean strength of the wires was reduced during the long period of storage by a maximum of 3%. For one rope, the mean strength of the wires increased by 2.7%.

1.1.2 Wire Manufacturing

After the rod has been patented in a continuous system, the wire diameter is reduced in stages by cold drawing or cold rolling, rolling especially for profile wires. Patenting is a heating process. First the wire is heated in an austenising furnace at about 900°C. Then the temperature is abruptly reduced to about 500°C when the wire is put through a lead bath. After remaining there for a while, the wire then leaves the bath and enters the normal temperature of the surroundings. Figure 1.2 shows the course of the temperature during the patenting process. In recent times, the patenting process has partly been replaced by cooling in several stages while drawing or rolling the rod, Marcol (1986).

By patenting, the steel rod gets a sorbite structure (fine stripes of cementite and ferrite) which is very suitable for drawing. In the following drawing process, the wire cross-section is reduced in stages, for example in seven stages from 6 to 2 mm in diameter. After the wires have been patented, they can be drawn again. The quality of the wire surface can be improved by draw-peeling the wire rod, Kieselstein (2005).

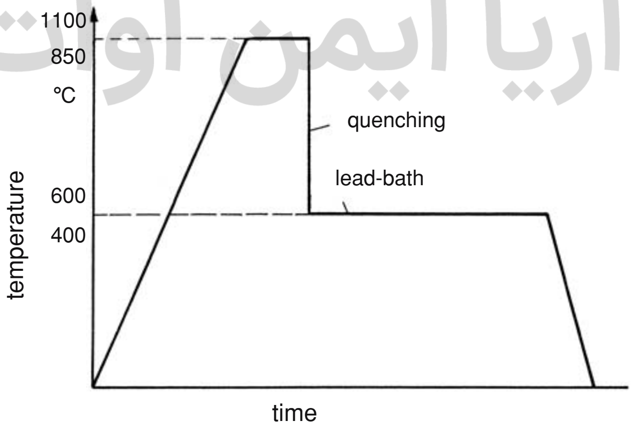

Fig. 1.2. The course of the temperature in the patenting process

The principle of the wire drawing was described at an early date by Siebel (1959). The strength increases with the growing decrease of the cross-section by drawing and at the same time the breaking extension also decreases. The higher the carbon content of the wires, the stronger they are. For wires with small diameters below 0.8 mm, the strength can reach about 4,000 N/mm^2, for thicker wires about 2,500 N/mm^2, and in all cases the remaining ductility is low. The standardised nominal strengths of rope wires are

- R_0 = 1,370 N/mm^2 (in special cases)
- R_0 = 1,570 N/mm^2
- R_0 = 1,770 N/mm^2
- R_0 = 1,960 N/mm^2
- R_0 = 2,160 N/mm^2 (with a smaller wire diameter)
- R_0 = 2,450 N/mm^2 (with a smaller wire diameter).

The nominal strength is the minimum strength. The deviation allowed above the nominal strength is about 300 N/mm^2. However, the real deviation is usually much smaller.

1.1.3 Metallic Coating

Rope wires needing to be protected against corrosion are normally zinc coated. Zinc coating provides reliable protection against corrosion. Even if the zinc layer is partly damaged, the steel remains protected as the electro-chemical process results in the zinc corroding first. With zinc, the wires can be coated by hot zincing or a galvanizing process. With hot zincing, the outer layer consists of pure zinc. Between this layer and the steel wire there is a boundary layer of steel and zinc compounds. With zinc galvanized wires, the whole layer of the coating, which can be relatively thick, consists of pure zinc and has a smooth surface.

In most cases the wires are covered by hot zincing. The layer of FeZn-compounds should be avoided or at least kept thin as they are relatively brittle which can lead to cracks when the wire is bent. To keep the FeZn layer thin, the wires should only be left in the zinc bath (with a temperature 440–460°C) for a short time.

During the hot zincing, the strength of the wires is somewhat reduced Wyss (1956). Because of this, and also because of the rough surface resulting from the zincing, the wires are often drawn again. This process increases the strength of the wire again and the zinc surface is smoothed. Before drawing, the zinc layer should be thicker than required as part of the zinc layer will be lost during the drawing process.

Blanpain (1964) found that during the re-drawing the brittle Fe–Zn layer may tear especially if the Fe–Zn layer is relatively thick. The resulting gaps will be entered from inside by a steel arch and are not visible from outside as they are closed with zinc. The fatigue strength of these wires is reduced due to the sharp edges of the gaps.

As an alternative to zinc, the wires can be coated with galfan, an eutectoide zinc–aluminiumalloy Zn95Al5 (95% zinc, 5% aluminium). Nünninghoff and Sczepanski (1987) and Nünninghoff (2003) found that this Zn–Alalloy offers better protection against corrosion than pure zinc. The Zn95Al5 coating also has the further advantage that the brittle Fe–Zn-layer is avoided. However, the Zn95Al5-layer is not as resistant to wear as the pure zinc layer which means that Zn95Al5-coated wires are not as suitable for running ropes.

In Table 1.2, the surface-related mass of zinc coating is listed as an excerpt of Table 1.1 of EN 10244-2 in different classes. For a very thick coating, a multiple of class A can be used, as for example A×3. A surface-related zinc mass of 100 g/m^2 means that the thickness of the zinc layer is about 0.015 mm. For the Zn95Al5 coating, EN 10244-2 provides nearly the same surface-related mass for the classes A, B and AB. Unlike EN 10244-2, in Table 1.2 and in the following the symbol δ is used for the diameter of the wire.

1.1.4 Corrosion Resistant Wires

In exceptional cases corrosion resistant wires (stainless steel) have been used as rope wires. Some corrosion resistant steels for wires are listed in Table 1.3 from prEN 10088-3: 2001. The steel names of these high alloy steels begin with the capital letter X. The following number gives the carbon content in % multiplied with the factor 100. Then the symbols and the contents in % of the alloy elements are given. For example, for the steel X5CrNiMo17-12-2 the contents are 0.05% carbon, 17% chromium, 12% nickel and 2% molybdenum.

Table 1.2. Surface-related mass of zinc coating (excerpt of EN 10 244-2)

Wire diameter (mm)	class				
	A (g/m^2)	AB (g/m^2)	B (g/m^2)	C (g/m^2)	D (g/m^2)
$0.20 \leq \delta < 0.25$	30	20	20	20	15
$0.50 \leq \delta < 0.60$	100	70	50	35	20
$1.00 \leq \delta < 1.20$	165	115	80	60	25
$1.85 \leq \delta < 2.15$	215	155	115	80	40
$2.8 \leq \delta < 3.2$	255	195	135	100	50
$4.4 \leq \delta < 5.2$	280	220	150	110	70
$5.2 \leq \delta < 8.2$	290	–	–	110	80

Table 1.3. Strength of drawn wires out of corrosion resistant steel (excerpt of prEN 10 088-3:2001, Table 1.8)

Steel name	steel number	strength range (N/mm^2)
X10CrNi18-8	1.4310	600–800
X5CrNiMo17-12-2	1.4401	900–1100
X3CrNiMo17-13-3	1.4436	1,000–1,250
X1CrNiMoCuN20-18-7	1.4547	1,400–1,700
X1CrNi25-21	1.4335	1,600–1,900

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