SPRING MATERIALS

The most important requirement for every spring material consists of withstanding the highest possible load while storing and releasing energy without becoming permanently deformed.

Since a plastic strain can not be excluded in general, this is accepted under certain boundary conditions up to the elasticity limit or yield point of the material. The metallic spring materials are of fundamental significance.

In the range of elastic strain of a material, Hooke’s law represents the hypothesis that the elongation $\varepsilon$ is proportional to the normal stress $\sigma$. The proportionality constant is the modulus of elasticity $E$.

$$\sigma = \varepsilon \cdot E$$

The torsion is described by the correlation between shear $\gamma$, shear stress $\tau$ and shear modulus $G$.

$$\tau = \gamma \cdot G$$

Therefore the capability of a spring material depends on the modulus of elasticity and the shear modulus being non-influenceable physical properties of the material. These properties define the stiffness of the material.

Beyond this causal connection between the elastic strain and the effective stress in the spring (preferably bending or shear stress) there are additional requirements for spring materials. For example, the reliability of dynamically loaded springs is achieved by the use of a material with a maximum possible fatigue strength. The material must hence be highly ductile and insensitive to notches and cracks.

The spring materials also have to respond to the requirements arising from:

- forming
- exposure to heat (see Figure 1)
- corrosion
Figure 1 Thermal resistance of spring materials

The working temperatures mentioned in the individual material tables are valid for high material loads without special requirements for relaxation. For further questions please contact our calculation service.

In special cases a defined electric conductivity or an exactly defined behavior at working temperatures other than room temperature (high temperature or cryogenic application, elasticity behavior as far as possible temperature-independent) may be required.

Important for spring design and production is the deformability of the spring material. As, especially for cold-formed springs, most spring materials are available in either a cold-worked or oil hardened and tempered condition, a high amount of deformability is required for the spring production. The ductility available in the material must permit the mechanical forming of helical springs, bending springs or wire-shaped springs.

Another important criterion for material choice is the required durability. Therefore, there is a distinction between static, quasi-static and dynamic loading.

A static load is given when there is a constant force over time being applied to a spring.

Quasi-static means a time-dependent load with a negligibly small stress range (less than 0.1 • fatigue strength) without abrupt load application and release or a total number of cycles less than $10^4$.

Dynamic stress is defined as a time-dependent load application on a spring that occurs either randomly (stochastic) or follows a harmonic change (e.g. sinusoidal). If the total number of cycles with such a characteristic is more than $10^4$ but less than $10^7$ then this is considered as the range of finite fatigue.
A spring whose total lifetime is required to be larger than $10^7$ cycles up to "infinity" is referred to as a spring having an infinite life.

For loads in the range of finite fatigue the corresponding finite fatigue diagrams and for high durability the infinite fatigue strength diagrams are decisive. However, it must be stated that these diagrams are valid normally for a sinusoidal load characteristic. For differing load types or special material grades it is recommended that you please contact our calculation service.

Measures to increase the durability are described in the Production - Shot Peening and the Production - Presetting sections.

The justifiable spring relaxation is of exceptional significance. Relaxation means the stress, temperature and time-dependent loss of load at constant assembly length. Relaxation diagrams for spring material can be found in the relating standards or material data sheets.

Possibilities for the reduction of relaxation are mentioned in the Production - Presetting section.

The criteria for choosing a spring material can be summarized as follows:

- extent and type of load
- geometrical conditions (spring length, assembly space etc.)
- working temperature requirements
- corrosion requirements
- material and production costs

The order of these criteria may vary according to the actual requirements. However, the material costs will often be a decisive factor.

**SPRING WIRES**

**PATENTED COLD DRAWN SPRING STEEL WIRE**

In the 1870s a specific heat treatment was introduced which preceded the wire drawing operation. This resulted in a considerable increase in quality. The material thus obtained was called patented cold drawn after the patent of an Englishman named William Smith.

During patenting, the pre-rolled or pre-drawn wire is heated to the hardening temperature and then is isothermally quenched to a temperature of 500 to 600 °C using a lead bath, salt bath or air. The result is a fine pearlitic structure. Afterwards the wire cross section is reduced to size by cold drawing. The cross section reduction amounts up to 80%. During this process the wire changes its characteristic properties like tensile strength, elastic limit, elongation, reduction in area and fatigue strength under alternating torsion and bending stress.

Patented cold drawn spring steel wire is described in EN 10270-1. This standard corresponds approximately to the American standards ASTM A 227 and ASTM A 228.
The following surface conditions are common for patented cold drawn spring steel wire:

- wet drawn
- dry drawn
- phosphate coated
- tin coated
- galvanized
- ZnAl coated

Galvanized wires are of special importance. In general, these spring wires are available in the range of 0.5 mm to 4.0 mm. Depending on the wire thickness, zinc coating from 45 g/m² to 150 g/m² (corresponds to a layer thickness of 8 µm to 20 µm) is possible.

Wire grade SL according to EN 10270-1
Wire grade SM according to EN 10270-1
Wire grade SH according to EN 10270-1
Wire grade DM according to EN 10270-1
Wire grade DH according to EN 10270-1

**OIL HARDENED AND TEMPERED SPRING STEEL WIRES**

Since cold drawing reduces the fatigue strength under alternating torsion of steel wire, material qualities were developed that are especially suitable for compression springs with high durability. After the wire has been drawn to the proper size, it is oil hardened and tempered to receive the properties necessary for its application.

High requirements are set in terms of decarburization and surface quality.

During processing, the greatest care must be taken to avoid damage. Springs are stress relieved after forming and often shot peened to improve the fatigue strength. Presently, almost only alloyed spring wires are used in oil hardened and tempered quality.

**Further developments with valve spring wire**

The current valve spring wire grades are more and more used in the shaved condition with a continuously inspected surface.

Shaving removes about 0.15 mm of the surface layer of the rod wire. After the heat treatment performed after shaving to reduce new hardened zones and stresses, the wire will be drawn to the final diameter. The shaved wire has about 10% higher fatigue strength. While surface defects in shaved wires have become less and less significant, non metallic inclusions near to the surface are increasingly encountered as failure cause.
For this reason, research was done on the reduction of the influence of inclusions. Because of this it is possible to use the SiCr alloyed valve spring wire VDSiCr for extremely high-loaded springs. In addition, the higher tensile strength goes along with increased durability.

Another increase of the durability of compression springs was achieved by optimizing the residual stresses in the spring using a special production process. The so-called SCHERDEL SOF process (stress optimized production) permits an additional increase of the fatigue strength by up to 10%.

Wire grade FDC according to EN 10270-2
Wire grade TDC according to EN 10270-2
Wire grade VDC according to EN 10270-2
Wire grade FDCrV according to EN 10270-2
Wire grade TDCrV according to EN 10270-2
Wire grade VDCrV according to EN 10270-2
Wire grade FDSiCr according to EN 10270-2
Wire grade TDSiCr according to EN 10270-2
Wire grade VDSiCr according to EN 10270-2
Wire grade FDSiCrV
Wire grade TDSiCrV
Wire grade VDSiCrV
Wire grade VDSiCrNiV

STAINLESS SPRING STEEL WIRE

Stainless spring steel wires are based on austenitic, chromium nickel alloyed steels which are cold worked to achieve a high tensile strength. These wires are used in a hard condition for spring production. The springs then are subjected to heat treatment. Heat treatment – i.e. stress relieving or precipitation hardening in the case of grade 1.4568 – can decisively influence the spring function.

For good corrosion resistance a bright surface of the springs is useful. This can be made by cleaning, pickling after stress relieving or a protective gas heat treatment. Electrolytic polishing increases the durability of stainless springs.

Wire 1.4310 NS according to EN 10270-3
Wire 1.4310 HS according to EN 10270-3
Wire 1.4401 according to EN 10270-3
Wire 1.4568 according to EN 10270-3
NON-FERROUS SPRING WIRE

Basically, non-ferrous materials are used only in exceptions to fulfill special operating conditions.

Copper wrought alloys are being less and less used in spring production. Only when good electrical properties are needed, they can hold their ground.

Nickel alloys usually are corrosion and high-temperature resistant materials, which should imperatively be treated according to the material data sheets of the manufacturer. Some nickel based alloys have a very constant shear modulus within a wide temperature range and therefore were used in the measuring technology. The increasing use of electronic measurement devices strongly reduces this field of application.

Springs made out of aluminum alloys normally are used only in cryogenic technologies as well as the aerospace industry. These alloys do not become brittle even at extremely low temperatures. Their favorable weight, however, is opposed to a larger required assembly space.

Titanium alloys have a favorable strength/weight ratio and are very corrosion resistant. They are suitable for both lowest of temperatures and heat resistant springs (at least up to a certain limit). Springs made out of titanium alloys are about two thirds lighter than steel springs. Aging can raise the tensile strength considerably.

Wire made out of copper alloy CW507L according to EN 12166
Wire made out of copper alloy CW452K according to EN 12166
Wire made out of copper alloy CW409J according to EN 12166
Wire made out of copper alloy CW101C according to EN 12166
Wire made out of nickel alloy 2.4669
Wire made out of nickel alloy 2.4632
Wire made out of aluminum alloy EN AW-7075 according to EN 1301
Wire made out of titanium alloy Ti-3Al-8V-6Cr-4Mo-4Zr

SPRING STRIPS

For the spring strips described in the following chapter, it is very important that the strength is taken into account when it comes to spring production since this parameter is decisive for both the fabrication technology as well as the spring function. Details can be taken from the cited standards.

UNALLOYED AND LOW-ALLOYED SPRING STEEL STRIPS

These spring strips are used in the spring hard (oil hardened and tempered) condition (material designation + QT) as well as in the soft condition, soft annealed (material designation + A) or soft annealed and lightly rolled (material designation + LC). For the oil hardened and tempered condition, oil hardening or isothermal hardening is possible.

The material condition to be chosen depends on the manufacturing process and the spring shape. The required values of hardness or tensile strength must be given at the time of order.
Oil hardened and tempered strips are available with different surface conditions such as:

- bright
- grey blue
- polished by grinding
- polished by brushing
- polished and tempered to color
- yellow

Strip 1.1231 according to EN 10132-4
Strip 1.1248 according to EN 10132-4
Strip 1.1269 according to EN 10132-4
Strip 1.1217 according to EN 10132-4
Strip 1.1274 according to EN 10132-4
Strip 1.1224 according to EN 10132-4
Strip 1.8159 according to EN 10132-4
Strip 1.2235 according to EN 10132-4

STAINLESS SPRING STEEL STRIPS

Stainless steel strips are normally used in the spring hard (cold rolled) condition. The heat treatment after spring production has a decisive influence on the spring function. For good corrosion resistance, a bright surface of the spring is important, which can be achieved by cleaning, pickling or protective gas stress-relieving.

Electrolytic polishing may increase the durability.

Strip 1.4301 according to EN 10151
Strip 1.4310 according to EN 10151
Strip 1.4369 according to EN 10151
Strip 1.4401 according to EN 10151
Strip 1.4568 according to EN 10151

NON-FERROUS SPRING STRIPS

Here only copper wrought alloys are listed that are used in the spring hard, i.e. cold rolled, condition. They have a higher tendency to creep because of their lower tensile strength compared to spring steel. While these materials have a good electric conductivity and a high corrosion resistance, durability and thermal stability are lower than in spring steels.

Strip made out of copper alloy CW507L according to EN 1654
Strip made out of copper alloy CW452K according to EN 1654
Strip made out of copper alloy CW409J according to EN 1654
Strip made out of copper alloy CW101C according to EN 1654

The precipitation hardenable CuBe alloys such as CW101C have a higher tensile strength. Nevertheless, their application is not permitted in many countries due to environmental protection reasons.