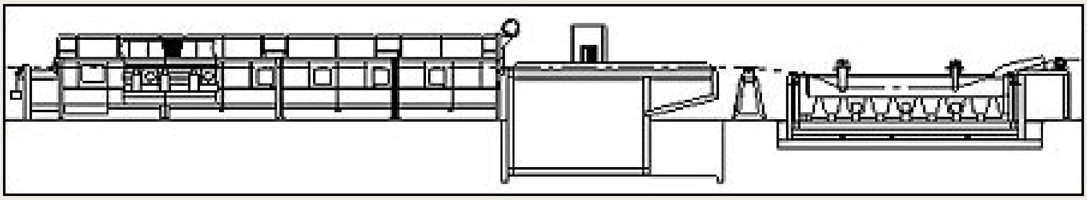
# *OIL TEMPERED WIRE*

**Oil tempering process is the term commonly used in the wire industry to designate a type of wire which receives a hardening and tempering treatment after it has been drawn to the desired size.**

**The term is in fact incorrect as the process consists of a heating above the critical temperature, one oil quenching and one reheating or tempering (usually in lead) to relieve the quench hardness obtained. Nowhere in the sequence is oil to be found as the tempering medium.**

**This type of wire is recognized by the springmakers because of its combination of excellent elastic properties and good toughness.**



**In that field, FIB has developed a concept of line where both the stability of the temperature of the equipments is taken into account as the cooling efficiency of the oil quenching bath. Our design of lines has successfully treated wire size from 0,3 mm up to XX mm.**

**In a world where the use of lead is more and more avoided, the fluidised bed has probably a place to be considered in that process.**

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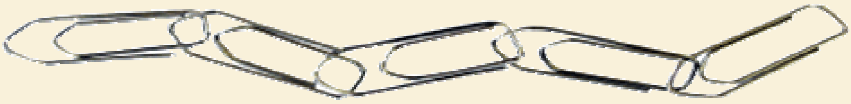
## Martensitic transformation - Nature of martensite and its properties :

**The martensite is a solid solution of supersaturated carbon solution in the iron a. The martensite is the main structure of the hardened steel, its properties and its transformations caused by a later heating determine on turn the properties and the behaviour of the steel.**

**The carbon atoms dissolved in the austenite network keep also their position in the network of iron a which they heavy perturb.**
**Martensite has a tetragonal pattern, a side of which (c) is bigger than the other (a). As the carbon content increases, the height of the tetragonal prism (c) is also quickly increased while the decreasing of the sizes of its base (a) is slow.**



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A greater carbon content in the martensite makes the report c/a greater, i.e. the tetragonal look of the pattern. When this content reaches 1,5 % C, c/a equals 1,06.

The crystals of the martensite have the form of small strips becoming thinner towards the ends. Their section by the plan of the cut confers to the martensite studied through a microscope a particular acicular structure.

The result of the heavy distortion of the crystalline pattern of the iron a by the inserted carbon atoms is that martensite has a high hardness and a weak plasticity.

The hardness of the martensite becomes higher when the carbon content increases.

The martensite is characterized by a weak resistance to the decohesion, a reduced breaking load and above all a low limit of elasticity, which is explained by an important state of constraint. The tensile tests of the steels with martensitic structure and with carbon content higher than 0.4 % involve a fragile breakage.

## Martensitic transformation :

Unlike the perlitic transformation, the martensitic transformation happens without diffusion. The mechanism of this system is limited to the reconstruction of the cubic pattern with centred faces of the austenite in centred cubic pattern (tetragonal).

To this aim it is sufficient that the bordering atoms are moving the ones in regard to the others at distances which do not exceed the interatomic distances. So the martensitic transformation modifies only the pattern without precipitating the carbon of the solution.

**The particular features of a martensitic transformation are :**

1) high speed of germination and of development of the germs at low temperature ; the duration of the formation of a martensitic crystal is varying from 0,5.10-7 to 5,7.10-8 Sec. according to its sizes, while the average speed of germination is of 106 mm/s

2) limited growth of the crystals which develop quickly up to a defined limit which put an end to their evolution

3) fast absorption of the transformation with the end of cooling.The enorm speed of the growth of the martensitic crystals at the relatively low temperatures is due to the fact that the moving of the atoms is very low and that the patterns of austenite and martensite are coherent.

The sizes of the crystals are determined by the sizes of the grain of primary austenite. They are all the more important since the austenite grains were big. The length of the first martensite crystal corresponds to the diameter of the austenite grain. The crystals which appear later are hindered in their evolution and are so clearly smaller.

The martensitic transformation is only possible in the case where the steel is cooled down at a sufficient speed for ensuring the overmelting of the austenite up to the low temperatures which prevent the starting of the diffusion phenomena.

The martensitic transformation begins at a defined temperature which is called beginning of the martensitic transformation and is designated as Ms. When the cooling is pushed below the Ms point, the austenite begins its transformation in martensite.

This phenomenon spread out on a large interval of temperatures ; as much the temperature is low in regard to Ms, as much there is formation of martensite. The quantity of martensite formed according to the temperature can be expressed by the martensitic curve (see herebelow).

Once a well defined temperature is reached, the decomposition of the austenite and the formation of the martensite come to an end. This temperature is called end of the martensitic transformation, it is noted Mj. The position of the points Ms and Mj does not depend on the cooling speed, it is determined by the chemical composition of the austenite. The more the carbon content of the austenite is high, the more the points Ms and Mj are low.

## Transformation of the martensite during the heating :

**The martensite with tetragonal pattern is a structure out of balance. The passage of the steel to a stabler state has to be accompanied of the decomposition of the martensite and of the formation of an aggregate ferrite + cementite. A solid solution decomposes by diffusion and therefore the speed of this phenomenon is determined especially by the heating temperature. The transformation begins from the ambient temperature.**

**Nevertheless under 60 to 80°C, the martensite decomposes very little and slowly. In the interval between 80 and 300°C, the decomposition becomes rather intense.**

**The solution a emits the carbon under the form of fragmented particles of iron carbide. Under 200°C is formed a carbide with hexagonal pattern of the type 8FexC (probably Fe2C). At 350 or 400°C, this carbide is transformed in cementite (Fe3C).**

## The decomposition of the martensite takes place in two steps :

- At the **first step** which is noticed at the temperatures lower than 150°C, the carbon necessary for the formation of the carbide is extracted only from the area of solid solution (martensite) adjacent to the crystals of the carbides already appeared. The concentration of the carbon in these area clearly decreases while the solid solution of the more distant volumes (martensite), obtained after quenching, keeps its initial concentration. The formation of the carbides at the first step of the martensitic decomposition is thus not accompanied with the moving by diffusion of the carbon atoms at important distances.So, after heating up to the low temperatures (under 150°C), the steel includes, in addition to the precipitated carbide particles, two solid solutions a (martensite) at high (initial) and low concentration of carbon.
As the heating up is intensified, the always continued precipitation of the carbides decreases continuously the quantity of solution a with a high C content while the quantity of solution with a low C content increases.

-The **second step** of the decomposition happens between 150 and 300°C. It consists in a always more pushed precipitation of the carbides from the solid solution (martensite) which is accompanied by the coalescence. The transformation takes place at a weak speed because the impoverishment of the solid solution in carbon is due to the enlarging (coalescence) of the carbide particles. The migration of the carbon within the solid solution has so to be effected by diffusion, very slow at the low temperatures. Under these conditions, the cohesion of the carbide patterns and of the solution a is not broken off.

The structure appeared after the decomposition of the martensite at temperatures higher than 300°C is called tempered martensite. It is a solid solution oversaturated of carbon in the iron a (of an heterogeneous concentration) including inclusions of fragmented carbide crystals bound by cohesion to the pattern of the solid solution a.

The tempered martensite keeps its acicular structure.

Between 300 and 350°C, the reticulated distance of the solid solution a merges with the one of the iron a (ferrite), which indicates that the part of carbon remaining in the solid solution a near its balance value. But the carbide crystals are still bound by cohesion to the pattern of iron a which keeps its elastical distortion.

The result of this is that a steel tempered between 300 and 350°C is composed of crystals of the solid solution a being subjected to an elastical deformation and of particles of cementite weakly dispersed in that solution. Such a structure is called tempered troostite.

## Coalescence of the carbides :

From 350 to 400°C, the end of the carbon precipitation in the solution a is accompanied by the breaking off of the cohesion and by the isolation of the patterns of ferrite and of carbide.

Higher temperatures start the coalescence detectable of the carbides. Not only they grow but even their shape is changing by transforming from thin splits to spherules.

The coalescence and the spheroidisation are determined by the decreasing of the interface between the phases and, therefore, of the free energy of the system.
The mechanism of the coalescence consists in a migration by diffusion of the carbon (through the solid solution) from small carbides towards bigger carbides.

**Between 500 and 600°C, the coalescence of the carbides transforms the troostite into sorbite which, at still higher temperatures, becomes perlite.**

**The carbides emitted by the tempering inside the old martensite crystals confere to the tempering products (troostite, sorbite) their orientation kept often to 500 or 600°C, as well as an acicular structure similar outside to that one of the martensite.**
**The carbides of troostite and of sorbite produced by the decomposition of the martensite, unlike the ones obtained after the transformation of the surfused austenite, have a globular and not lamellar structure.**

### Influence of the transformation on the properties :

**The formation of the globular structures is favourable to the numerous properties of the steel. The figure hereunder compares the mechanical properties of a steel with lamellar structure obtained by isotherm decomposition of the overmolten austenite and the mechanical properties of a steel with globular structure formed by transformation of the martensite. The hardness, the breaking load and the elongation being the same for the both kinds of steel, the values of the conventional limit of elasticity and of the necking down are higher for a steel with globular structure.**

**The decomposition of the martensite during the tempering has a heavy influence on all the properties of the steel. At the low temperatures (200 to 250°C), the hardness does not many change. Nevertheless, the real resistance to tensile strain and the bending strength increase, which is explained by the weakening of the constraints which sollicitate the martensitic pattern owing the emission of carbon.**
**By pushing the tempering temperature above 200 to 250°C, the hardness, the breaking load and the conventional elasticity limit are reduced while the elongation and the necking down are increased.**
**The elasticity limit reaches a maximal value after tempering of 250 or 300°C.**