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# Drawability of steel wire

*Dipl Ing Met A Robonyi

**The simple formulae presented in this article are the result of comprehensive data collection and analyses carried out over several decades. Ductility and other important mechanical parameters of a drawn wire are calculated on the bases of the chemical composition and the most important manufacturing conditions of non-alloyed steel wires.**

Ductility is a function not only of the basic material but also the forming technology and conditions. Drawability of non-alloyed steel wires depends on the structure and technological parameters of forming. (When saying that, it is assumed that the basic material is free of defects and the surface treatment of the wires to be drawn is near perfect; this will be assumed throughout this article). Furthermore, the behaviour during drawing of wires with a structure produced by patenting will be discussed.

### Temperature of austenitisation

It is of the upmost importance that an austenitic structure consisting of homogenous and uniform grain sizes is produced. If a diagram is not available for the continuous austenitising of the steel quality concerned, the minimum temperature required can be calculated as follows:

$$t\gamma = t_{GOS} + \Delta t_1 + \Delta t_2 \qquad (°C)$$

$$\Delta t_1 = 13 \left(\frac{°C}{S}\right)^{0.45} \qquad (°C)$$

$$\Delta t_2 = \frac{492 + 15.C^{-1}}{\sqrt{t_{GOS} + t_1 - 23}} \qquad (°C)$$

where:

$t_{GOS}$ — temperature $A_3$ is a function of the carbon content in the Fe-C constituent diagram.

$\left(\frac{°C}{S}\right)$ — rate of heating. (This can be determined empirically taking into account the following parameters; construction of the heating furnace; rate of pulling through; determination of dwell period at temperature.)

C — carbon content of the wire (%)

When austenitising, the temperature applied in practice ($t_{ausz}$) is greater by about 70-100°C than the tγ value calculated in this way, depending on the heat transfer parameters of the furnace.

### Temperature of transformation

The transformation temperature is mainly a function of wire diameter and the temperature of the quenching lead bath. Mean temperature of transformation can be determined by the following formula:

$$t_{at} = t_{Pb} + 0.22 \; \frac{\log n\,(t_{GOS} + \Delta t_l)}{\log n\,(t_{ausz})} \; . \; (723 - t_{Pb}) \; . \; \log n\,(d) \qquad (°C)$$

where:

$t_{at}$ — temperature of transformation in the pearlitic range (°C)

d — diameter of wire being heat treated (mm)

$t_{Pb}$ — temperature of lead bath (°C)

The value of the over quenched temperature is:

$$\Delta t = 723 - t_{at} \qquad (°C)$$

As a result of patenting performed with the above mentioned parameters the most important mechanical and quality features of the non-alloyed steel wires will be the following:

Tensile strength of the wire:

$$R_m = 294 + 679.C_o + S^{-3/4}\,(9110\,.\,C_e + 3950) \qquad \text{(Mpa)}\; r = 0.93$$

Its contraction:

$$Z = 320\,.\,S^{-1/2}\,.\,(2.0 - C_e) \qquad (\%)\; r = 0.63$$

Average thickness of pearlite plates:

$$S = 1190\,.\,(\Delta t)^{-1/2}\,.\,(2.5 - 1.5\,.\,C_e) \qquad \text{(nm)}$$

In these formulae the equivalent carbon content is:

$$C_e = C_{\%} + \frac{Mn\ \%}{5}$$

(In the tests carried out, materials with $C_{\%} \geq 0.12\%$ were used).

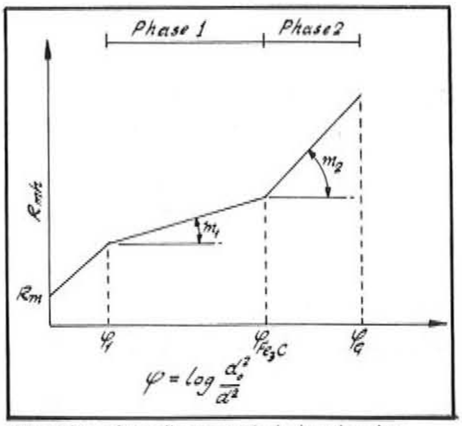
The relationships presented above describe the correlations between the characteristics of the material and its heat treatment, that is between patenting and features of the patented wire.

Stress distribution in the material of a wire drawn through a die is very complex. Distribution of stresses and the rate of deformation are different in several layers of the wire.[2] Influenced by the real value of these parameters the deformation starts differently in the randomly orientated pearlite grains.

In groups consisting of pearlite plates orientated parallel to the centre line of drawing, the thicknesses of the pearlite plates first begin to decrease by deformation and only after about a 55-60% deformation do the cementite plates start to break.[3]

Pearlite plates orientated perpendicular to the direction of drawing will be bent and corrugated, and their virtual thickness increased during deformation. By increasing the deformation further they will be rotated into the direction of drawing.

Behaviour of pearlite groups orientated between the two extremes can be concluded from the deformation described above.




*Alteration of tensile strength during drawing*

Only after being rotated into the direction of drawing do the pearlite plates start to break in large quantities. (In the case of very thick pearlite plates, such damage can occur in such large numbers that the structure of the material appears to be globular and so the second phase of hardening might begin with a decrease in strength).

The changes described above can be followed clearly by testing the tensile

*'December 4' Wire Works, 3501 Miskolc, Besenvöi Út 16, Postbox 17, Czechoslovakia.

strength changes during drawing a wire. The nature of the changes is represented schematically in the illustration.

It is essential in wire drawing to determine the most important break points of the hardening curve based on the quality demands for the wire concerned. The starting point of Phase 1 is very important because the value of the $\Phi_1$ parameter must be correctly chosen. If it is too small a value a central crack might occur within the wire, and if it is too large, the drawability of the wire is radically reduced for the later phases of deformation.

It is also important to determine the starting point $\Phi_{Fe_3C}$ of Phase 2, since the ductility characteristics of the wire improve up to this point with increasing tensile strength (eg, the number of bends increases and after a slight deterioration the number of twists increase also). Deforming the wire above the value defined by $\Phi_{Fe_3C}$, the ductility characteristics are reduced and it can be a radical reduction too, at the same time the characteristics became unstable. (There is too large a variation around the mean value).

The above mentioned important points can be determined in the following way:

$$\Phi_{Fe_3C} = \frac{19}{\sqrt{S}} . (Co)^{-3/4} . \sqrt{\frac{t_{ageing}}{\bar{t}_{al}}}$$

$$r = 0.82$$

if $\bar{t}_{al} < t_{ageing}$ the value of this fraction is regarded as being equal to one, then:

$$\Phi G = \Phi_{Fe_3C} + \sqrt{\Phi_{Fe_3C}}^{\;\Phi_{Fe_3C}}$$

$$r = 0.67$$

where $\Phi_{Fe_3C}$ is the starting point of Phase 2 in the hardening curve.

$\Phi G$ — limit value for the economic drawability determined without too many breakages during drawing

$t_{ageing}$ — ageing temperature typical for the wire material concerned (generally 150-200°C)

$\bar{t}_{al}$ — mean temperature during deformation.

Example:

$$t_b = \frac{k_{fm} [\Phi + (\alpha + \sigma)]}{m . C . \gamma}$$

but if partial reduction analyses only are carried out:

$$\bar{t}_{al} = 0.32 . \sqrt{R_{mhe}} . (6 + 0.45 . \varepsilon \%) \quad (°C)$$

where $R_{mhe}$ is the tensile strength before drawing (MPa),

$$\varepsilon = \text{partial reduction} = \frac{d_x^2 - d_{x+1}^2}{d_x^2} .100 \quad (\%)$$

These relationships describe the important features of patenting and drawing, and give a simple correlation between several quality demands expected from the wire produced. Also, it might be interesting to determine the expected value of the tensile strength of the drawn wire.

The following relationships can be used to determine the tensile strength:

$$R_{mh} = Rm + 600 . \Phi_1 + m_1 . (\Phi_{Fe_3C} - \Phi_1) + m_2 (\Phi - \Phi_{Fe_3C}) \quad (MPa)$$

and if during production $\Phi \leqslant \Phi_{Fe_3C}$ (which is characteristic of a good wire) then:

$$R_{mh} = Rm + 600 . \Phi_1 + m_1 (\Phi - \Phi_1) \quad (MPa)$$

where:

$$m_1 = 165 . C_{\%} + 255 \qquad r = 0.89$$

$$m_2 = 625 + 25 . C_{\%} \qquad r = 0.72$$

It can be seen clearly from the above relationships that the carbon content of the wire has to be taken into account (as an influencing parameter in hardening) only in Phase 1.


## Summary

The behaviour of non-alloyed patented steel wire during drawing was investigated and relationships found between the important material features (C%, Mn%, d) and production parameters ($t_{ausz}$, $t_{Pb}$, $\bar{t}_{al}$, $t_{ageing}$). These relationships can be very useful in planning the production of wire possessing large enough ductility margins if the parameters of the manufacturing equipment are known and taken into consideration.



### References

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