# THE INFLUENCE OF COOLING CONDITIONS ON PEARLTE MORPHOLOGY OF HIGH CARBON WIRE RODS

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**Abstract**

The high carbon steel rods are designed for the manufacture of wire on the rope and steel cords. They are produced in continuous rolling mills with accelerated cooling device. High carbon wire rods should have a uniform pearlitic structure at cross section and a longitudinal which guarantees high tensile strength and relatively good plasticity. In practice rolled high carbon steel rods (0.40 ÷ 0.94 %C) should have a uniform pearlite structure with uniformly distributed cementite plates having a thickness of 0.02 ÷ 0,04 μm and the distances between the plates at 0.1 ÷ 0.2 μm. That type of pearlitic structure should ensure good plasticity [1].

The paper presents results of research on the influence of cooling conditions of high carbon wire rods (C70D and C46D according EN 10016-2) on the morphology of pearlite. For thermo-plastic treatment a deformation dilatometer DIL 805A / D were used. The samples after deformations were cooled to temperature to obtain pearlitic structure. The metallographic analysis of samples were done and morphologies perlite were determined. As a result of the research was to describe the dependence of the distance inter plates (Lm) as a function of the cooling rate after deformation. It will be used to the design high carbon wire rods cooling technology with high level of plasticity after rolling processes.

**Keywords:** High carbon wire rods, pearlitic morphology, distance between cementite plates

## 1. INTRODUCTION

The high carbon steel rods are designed for the manufacture of wire on the rope and steel cords should have a uniform pearlitic structure at cross section and a longitudinal which guarantees high tensile strength and relatively good plasticity. Wire rod without pure pearlitic structure before drawing must be patented. Wires obtained from patented wire rod are characterized by better properties than the wire rods obtained from other heat treatments. The structure of patented wire as compared to the wire obtained from the wire rod rolled with heat treatment in the production line is characterized by a smaller thickness of cementite platelets. Increased stiffness of thick plates of cementite, in the untreated wire rod patenting, leads to increased consolidation of ferrite. In practice high carbon steel rod rolling process should have a uniform pearlite structure with uniformly distributed cementite plates having a thickness of 0.02 ÷ 0.04 μm and the distances between the plates at 0.1 ÷ 0.2 μm. That type of pearlitic structure ensures good plasticity. In industrial conditions quality of patenting is determined by the tensile strength of the wire after patenting $R_{mp}$ dependent on the contents of C [2].

$$R_{mp} = 1000\,C + 500\,[MPa] \tag{1}$$

where: $C$ - the percentage of carbon.

Patented wire rods should not have even small amounts of martensite, ferrite precipitates on the grain boundaries at both cross-sectional and longitudinal directions. Properly selected cooling parameters should prevent the formation of hard structures (martensite and bainite) and ensure that the actual structure of pearlite interlamellar distance to 0.2 μm. Subsequent rapid cooling reduces the amount of cementite. In the process of drawing cementite and pearlite have different way of elongation, consequently, can be formed microcracks, which adversely affect the quality of the finished wire. Well-designed cooling process allows obtain a uniform pearlitic structure at cross section and a longitudinal [3].

## 2. EXPERIMENTS

Analysis of the actual manufacturing conditions of high carbon wire rod showed that the rolling end temperature depends on the final diameter is in the range 880 ÷ 950 °C. After rolling wire rods are cooled in air accelerated cooling process. In work parameters of cooling conditions for determine of pearlitic structure were obtained [1]. For determine the influence of cooling conditions of high carbon wire rods (C70D and C46D) on the morphology of pearlite deformation dilatometer DIL 805A / D was used [4, 5, 6]. The thermo-plastic treatment was done. The temperature of the end of the deformation adopted 900 ºC. For reproducing the history of deformation during the test samples were heated to a temperature of 1050 ºC at a heating rate of 10 °C / s, annealed at this temperature for 10 minutes and then cooled at a cooling rate of 10 °C / s to the temperature of the beginning of deformation. Three steps of deformation was applied strain $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0.25$ at a deformation rate of 10 $s^{-1}$ in temperatures of 970 ºC, 930 ºC and 900 ºC intermittently between strain 0.2 s. After that the samples were cooled with different cooling rates in the range of 0.1 ÷ 10°C / s. The range of cooling rate was determinated using DTTT diagram (Time-Temperature-Transformation diagram after Deformation) and guaranteed to achieve the ferritic- pearlitic structures. The **Fig. 1** shows a diagram of thermo - plastic treatment.

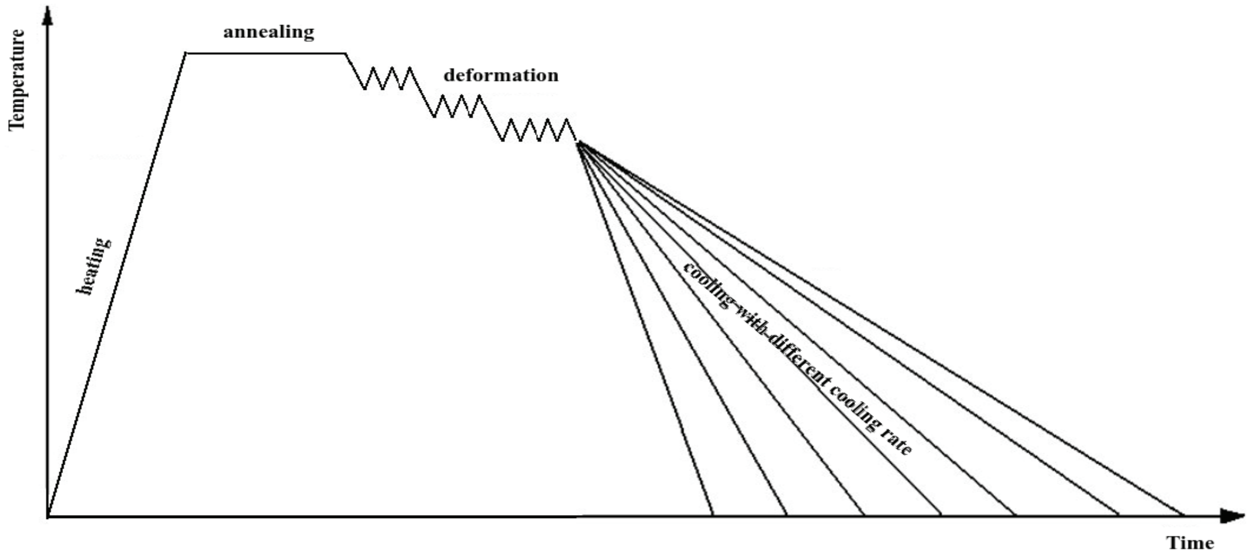


**Fig. 1**. The diagram of thermo - plastic treatment

The metallographic analysis of samples was done and morphologies of perlite were determined. For metallographic observation Hitachi S4200 scanning electron microscope was used. Based on recorded photos morphology of pearlite were done. The distance of plates of cementite after deformation and cooling were determined.

## 3. RESULTS

Using Hitachi S4200 scanning electron microscope a thickness of cementite plates and distance inter plates of cementite were determined. The exemplary structures of the C46D grade steel are presented in **Fig. 2**. The results obtained by scanning electron microscope observation C46D steel are given in **Table 1**.

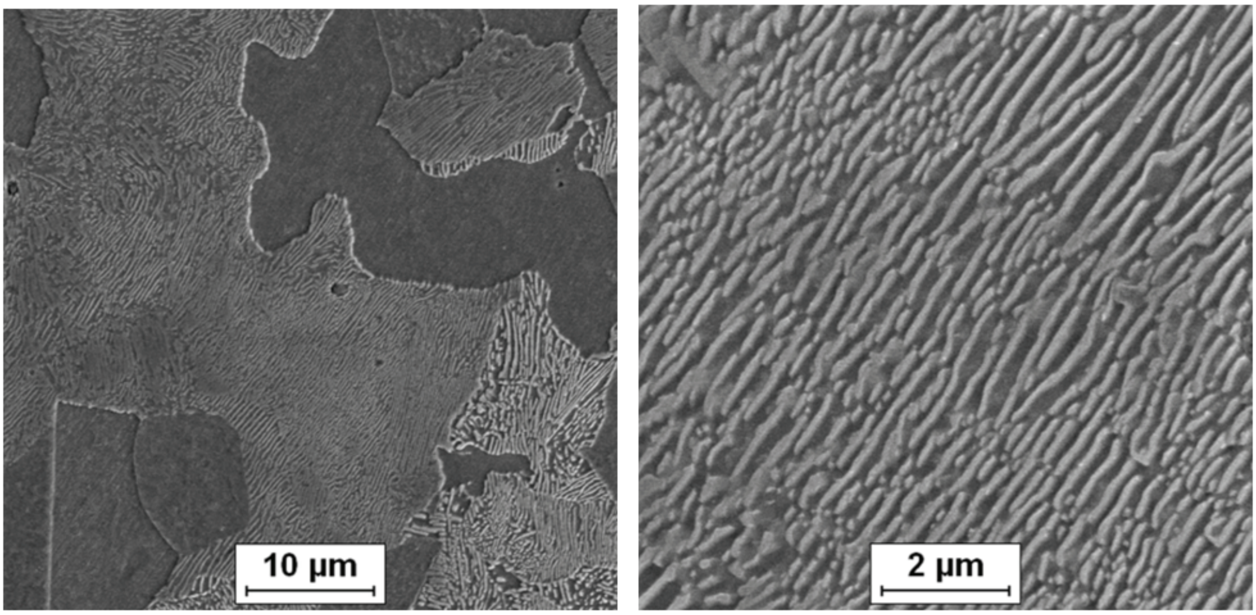


**Fig. 2** Microstructure of C46D grade steel cooled after deformation steps with cooling rate 1 °C / s

**Table 1** The results of quantitative assessment of pearlite plates of C46D steel after the simulation of thermo-plastic with a variable cooling rate

| Cooling rate after deformation ° C/s | Medium distance inter plates $L_m$ [µm] | Minimal distance inter plates $L_{min}$ [µm] | Maximal distance inter plates $L_{max}$ [µm] |
|---|---|---|---|
| 0.1 $s^{-1}$ | 0.389 | 0.052 | 0.790 |
| 1 $s^{-1}$ | 0.259 | 0.080 | 0.721 |
| 2.5 $s^{-1}$ | 0.275 | 0.082 | 0.591 |
| 5 $s^{-1}$ | 0.264 | 0.058 | 0.626 |
| 7.5 $s^{-1}$ | 0.239 | 0.076 | 0.621 |
| 10 $s^{-1}$ | 0.192 | 0.066 | 0.476 |

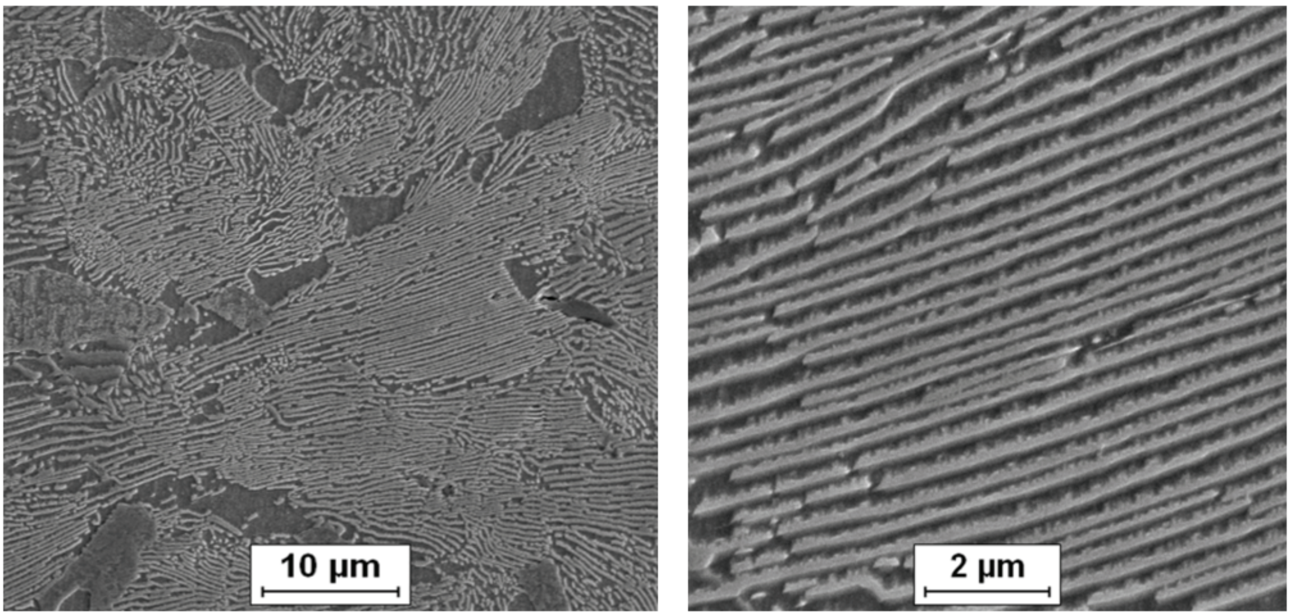


**Fig. 3** Microstructure of C70D grade steel cooled after deformation steps with cooling rate 1°C / s

The exemplary structures of the C70D grade steel are presented on **Fig. 3**. The results obtained by scanning electron microscope observation C70D steel are given in **Table 1**.

**Table 2** The results of quantitative assessment of pearlite plates of C70D steel after the simulation of thermo-plastic with a variable cooling rate

| Cooling rate after deformation ° C / s | Medium distance inter plates $L_{śr}$ [µm] | Minimum distance inter plates $L_{min}$ [µm] | Maximal distance inter plates $L_{max}$ [µm] |
|---|---|---|---|
| 0.1 $s^{-1}$ | 0.425 | 0.103 | 0.899 |
| 1 $s^{-1}$ | 0.,242 | 0.093 | 0.643 |
| 2.5 $s^{-1}$ | 0.191 | 0.083 | 0.421 |
| 5 $s^{-1}$ | 0.203 | 0.075 | 0.569 |
| 7.5 $s^{-1}$ | 0.189 | 0.061 | 0.471 |
| 10 $s^{-1}$ | 0.162 | 0.056 | 0445 |

Based on results of quantitative assessment of pearlite plates the formula for describing the dependence of the medium distance inter plates as a function of the cooling rate after deformation was obtained (**Fig. 4**). To describe the changes in the distance inter-plate power law equation was used. For steel C46D equation 1 was developed, and the standard deviation was $R^2$ = 0.86.

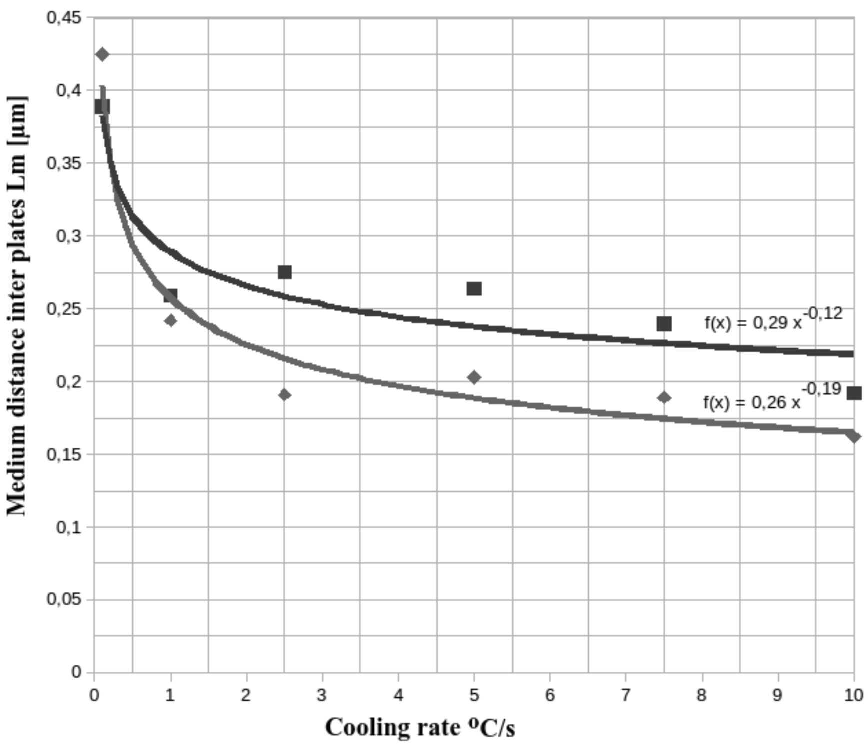


**Fig. 4** The changes of medium distance inter plates as a function of cooling rate

$$L_m(Cr)_{C45} = 0{,}29\,Cr^{-0{,}122} \tag{1}$$

For steel C70D equation 2 was developed, and the standard deviation was $R^2$ = 0.94.

$$L_m(Cr)_{C70} = 0{,}26\,Cr^{-0{,}19} \qquad (2)$$

where:

$L_m(Cr)$ - medium distance inter plates as a function of the cooling rate, µm;

Cr - cooling rate, °C / s

## 4. SUMMARY

For determine the influence of cooling conditions of high carbon wire rods (C70D and C46D) on the morphology of pearlite thermo-plastic modelling, using deformation dilatometer DIL 805A / D were done. After deformation samples were cooled down with different cooling rates in the range of 0.1 ÷ 10°C / s. Metallographic tests were done and morphology of pearlite were done. The study shows that the optimum cooling rate for C46D steel should be between 7.5 ÷ 10 °C / s, and 4.5 ÷ 10 °C / s for C70D steel. This cooling conditions guarantee the formation of pearlitic structures with the average distance interlamellar equal to, or less than 0.2 µm.

As a result of the research dependencies of the distance inter plates (Lm) as a function of the cooling rate after deformation analysing steel were obtained. They will be helpful to the design high carbon wire rods cooling technology with high level of plasticity after rolling processes.

## ACKNOWLEDGEMENTS

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