

S. WIEWIÓROWSKA*[‡], Z. MUSKALSKI*

THE ASSESSMENT OF THE STRUCTURE AND PROPERTIES OF HIGH-CARBON STEEL WIRES AFTER THE PROCESS OF PATENTING WITH INDUCTION HEATING

OCENA STRUKTURY I WŁASNOŚCI DRUTÓW ZE STALI WYSOKOWĘGLOWYCH PO PROCESIE PATENTOWANIA Z INDUKCYJNYM NAGRZEWANIEM

One of the most important types of heat treatment that high-carbon steel wires are subjected to is the patenting treatment. This process is conducted with the aim of obtaining a fine-grained uniform pearlitic structure which will be susceptible to plastic deformation in drawing processes. Patenting involves two-stage heat treatment that includes heating the wire up to the temperature above A_{C3} in a continuous heating furnace (in the temperature range of $850\div 1050^{\circ}\text{C}$) followed by a rapid cooling in a tank with a lead bath down to the temperature range of $450\div 550^{\circ}\text{C}$. The patenting process is most significantly influenced by the chemistry of the steel being treated, as well as by the temperature and the rate of heating and cooling of the wire rod or wire being patented.

So far, heating up to the austenitizing temperature has been conducted in several-zone continuous gas-fired or electric furnaces. Recently, attempts have been made in a drawing mill to replace this type of furnace with fast induction heating, which should bring about an energy saving, as well as a reduced quantity of scale on the patented wire.

This paper presents the analysis of the structure and mechanical properties of wires of high-carbon steel with a carbon content of 0.76% C after the patenting process using induction heating for different levels of the coil induction power.

Keywords: wires, patenting process, induction heating

Jednym z najważniejszych rodzajów obróbki cieplnej jakim poddaje się druty ze stali wysokowęglowych jest zabieg patentowania. Proces ten prowadzi się w celu otrzymania drobnoziarnistej, jednolitej struktury perlitycznej, która będzie podatna na odkształcenia plastyczne w procesach ciągnięcia. Patentowanie polega na dwustopniowej obróbce cieplnej składającej się z procesu nagrzewania drutu do temperatury powyżej A_{C3} w piecu grzewczym przelotowym (zakres temperatur $850\div 1050^{\circ}\text{C}$) i następnie szybkim schłodzeniu w wannie z kąpielą ołowiową do zakresu temperatur $450\div 550^{\circ}\text{C}$. Na proces patentowania najistotniejszy wpływ ma skład chemiczny obrabianej stali a także temperatura i szybkość nagrzewania oraz chłodzenia patentowanej walcówki lub drutów.

Dotychczas nagrzewanie do temperatury austenitizacji realizowane jest w kilkustrefowych przelotowych piecach gazowych lub elektrycznych. Ostatnio w jednym z zakładów ciągarskich podjęto próby zastąpienia tego typu pieca szybkim nagrzewaniem indukcyjnym, co powinno zaowocować oszczędnością energii, jak i mniejszą ilością zgorzeli na patentowanych drutach.

W pracy przedstawiono analizę struktury i własności mechanicznych drutów ze stali wysokowęglowej o zawartości 0.76% C po procesie patentowania z wykorzystaniem indukcyjnego nagrzewania dla różnych poziomów mocy wzbudzenia induktora.

1. Introduction

Wires of high-carbon steel with a carbon content of approx. 0.76% C designed for hoisting ropes to be used in the mining industry should have the proper tensile strength, i.e. 1800 ± 100 MPa [1].

Because of the fast strain hardening of high-carbon steel, the majority of finished wires cannot be obtained directly from wire rod, but instead from intermediate wire pre-drawn to a diameter of about $4.50\div 3.50$ mm. The intermediate wire must therefore undergo the patenting process to eliminate the cold work effects and to obtain a material structure susceptible to

large plastic deformations of up to 95%, consisting of fine pearlite with a high scattering of dispersion cementite [2].

Patenting consists in two-stage heat treatment. At the first stage, the process of wire annealing is conducted at the temperature above A_{C3} , i.e. in the temperature range from 850 to 1050°C . The next stage of the patenting process is an isothermal cooling at the temperature of approx. $450\div 550^{\circ}\text{C}$ in a lead bath tank or in a fluidized-bed furnace [3].

Normally, the first phase of the process is carried out by heating the wire in a several-zone continuous furnace. The disadvantage of this process is that obtaining a high austenitizing temperature being uniform on the wire cross-section requires an adequate duration, and despite the large length

* FACULTY OF PRODUCTION ENGINEERING AND MATERIALS TECHNOLOGY, CZESTOCHOWA UNIVERSITY OF TECHNOLOGY, 19 ARMII KRAJOWEJ AV., 42-200 CZESTOCHOWA, POLAND

[‡] Corresponding author: wiewior@wip.pcz.pl

of the equipment involved, presents a major limitation on its productivity [4].

An attempt has been made in a drawing mill to substitute the continuous furnace wire heating with a fast induction heating. This wire patenting technology enables the wire to be heated fast and uniformly over its entire cross-section and minimizes the adverse effect of the continuous furnace wire heating process, which is the formation of scale on the wire surface.

The variable parameter in tests was the magnitude of a coil induction power. The purpose of the study was to determine whether the induction heating would result in the wire having a structure and mechanical and plastic property levels similar to those obtained as a result of the traditional patenting technology.

2. Testing material

Tests were conducted for high-carbon steel in C76D grade with chemical composition as shown in Table 1.

TABLE 1
The chemical composition of steel, %

C	Mn	Si	P _{max}	S _{max}	Cr _{max}	Ni _{max}	Mo _{max}	Cu _{max}	Ni _{max}
0.73÷ 0.78	0.50÷ 0.80	0.10÷ 0.30	0.03	0.03	0.15	0.20	0.05	0.25	0.01

Intermediate wire with a diameter of 4.00 mm was used for the tests.

The variable parameter in the tests was the level of coil induction power (Table 2), and the results obtained from the examination of induction heated wires were compared with the properties of wires obtained from the patenting process using continuous furnace heating.

TABLE 2
Coil induction power in the induction heating test

Specimen No.	Coil induction power [kW]
1	12
2	8
3	6

3. Original investigation

The mechanical testing of wires after the patenting process was completed following the conventional technology and after the patenting process with induction heating for varying coil induction power levels was carried out on a ZWICK/Z100 testing machine, and the obtained results are represented in Figs. 1-2.

The analysis of the investigation results found that the magnitude of the tensile strength R_m for the wires patented under induction heating conditions for the induction power values of 12 and 8 kW was almost the same and by approx. 80 MPa lower than for the wires patented according to the conventional technology.

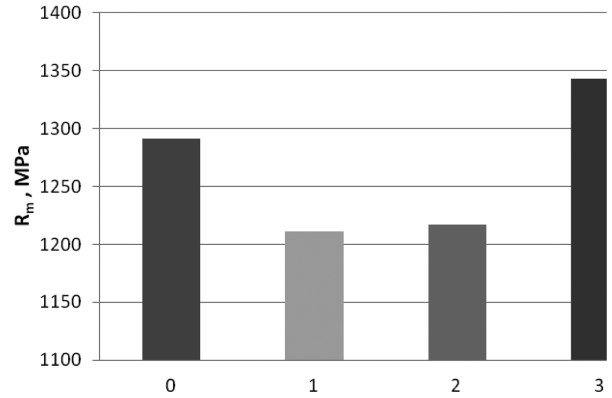


Fig. 1. The tensile strength R_m for the wire patented following the conventional technology (specimen no. 0) and under induction heating conditions (specimens nos. 1, 2, 3)

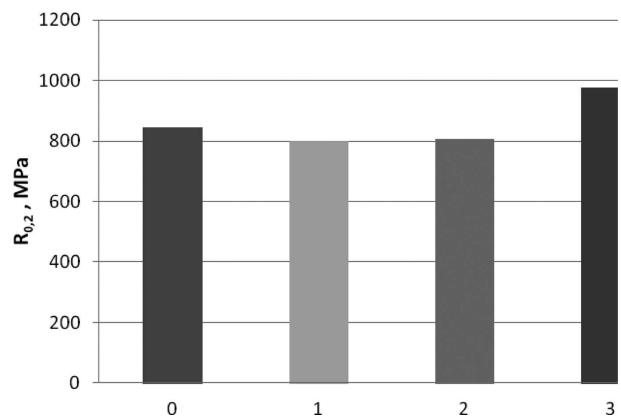


Fig. 2. The offset yield strength $R_{0.2}$ for the wire patented following the conventional technology (specimen no. 0) and under the induction heating conditions (specimens nos. 1, 2, 3)

Whereas, the R_m values obtained for the wires patented under induction heating conditions for the induction power equals to 6 kW are the highest, amounting to approx. 1340 MPa.

The same relationship occurred for the values of the offset yield strength $R_{0.2}$.

To determine the susceptibility of the drawn wires to a cold plastic deformation, the value of the so called "plasticity reserve", or the $R_{0.2}/R_m$ ratio, was also analyzed; the examination results are illustrated in Fig. 3.

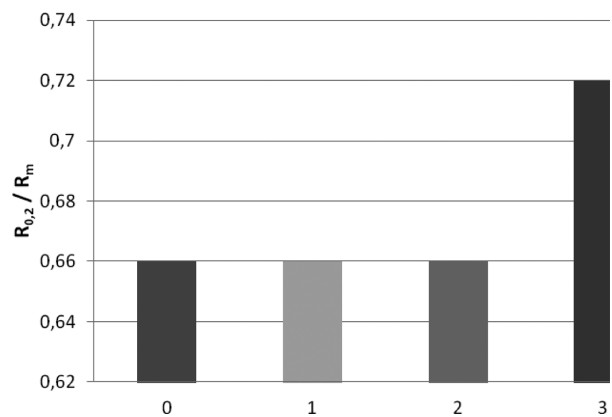


Fig. 3. The value of the $R_{0.2}/R_m$ ratio for the wire patented following the conventional technology (specimen no. 0) and under the induction heating conditions (specimens nos. 1, 2, 3)

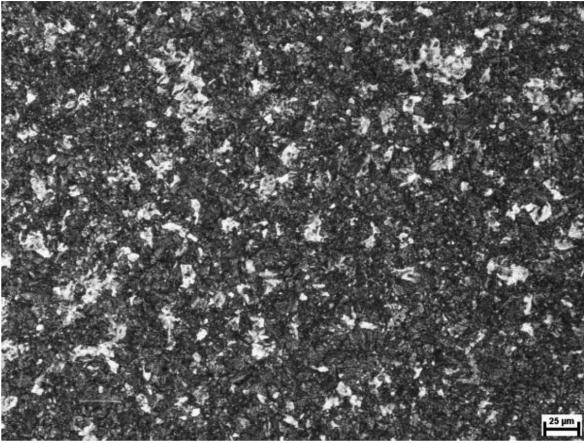


Fig. 4. Structure of the wire after patenting following the conventional technology – specimen no. 0; (etched with Nital)

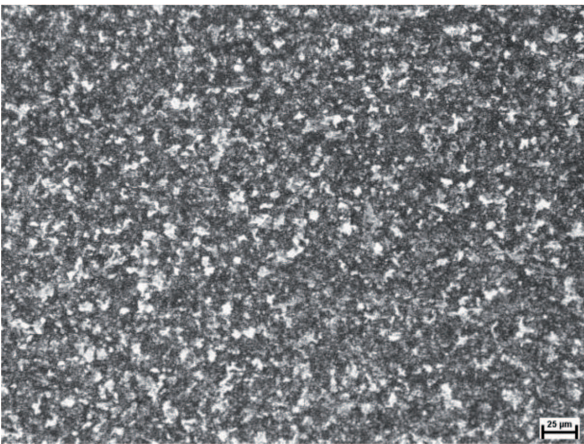


Fig. 5. Structure of the wire after patenting with the induction heating (12 kW) – specimen no. 1; (etched with Nital)

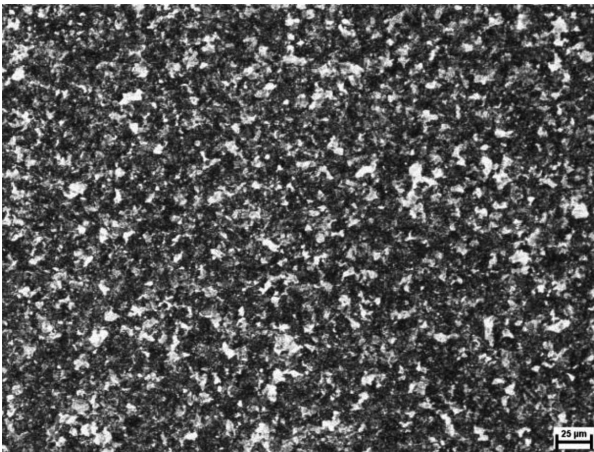


Fig. 6. Structure of the wire after patenting with the induction heating (8 kW) – specimen no. 2; (etched with Nital)

The $R_{0.2}/R_m$ ratio value is similar for the wires from variants 0, 1 and 2, but much greater for the wires patented under the induction heating conditions for the induction power equals to 6 kW. It was therefore concluded that the coil induction power used in this case was not sufficient for producing the wires with the adequate "plasticity reserve".

To determine the material structure after patenting according to the respective variants, microstructural examina-

tions were performed using an Axiovert 25 optical microscope (Figs. 4÷7).

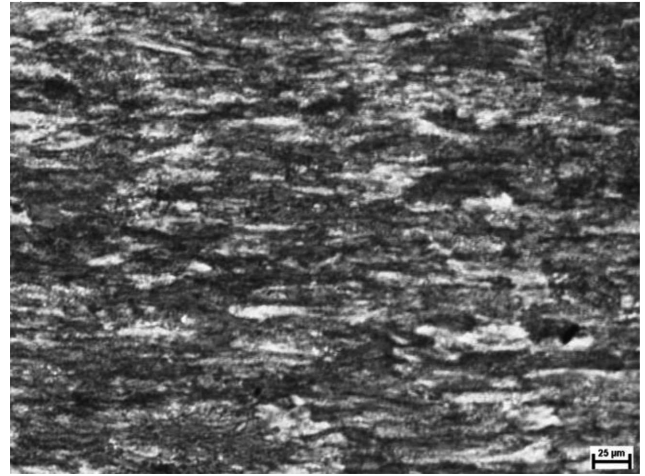


Fig. 7. Structure of the wire after patenting with the induction heating (6 kW) – specimen no. 3; (etched with Nital)

From the investigation carried out it has been found that the process of patenting using induction heating for the coil induction power equals to 12 and 8 kW enables wires to be produced, which are characterized by the adequate refinement of the microstructure (Figs. 5 & 6), similar to the one obtained from patenting following the conventional technology (Fig. 4).

The magnitude of the coil induction power being equal to 6 kW, on the other hand, is not sufficient for the complete structure recrystallization and removal of the cold work effects that have resulted from the previous drawing process. This is suggested by the structure banding and the strong grain elongation (Fig. 7).

As we know, the patenting process is conducted with the aim of obtaining a fine-dispersion pearlite structure with distances between cementite lamellas of about $1\mu\text{m}$. Therefore, a microstructural analysis was made for specimens nos. 1 and 2 using a JSM-5400 scanning microscope (Figs. 8 and 9).

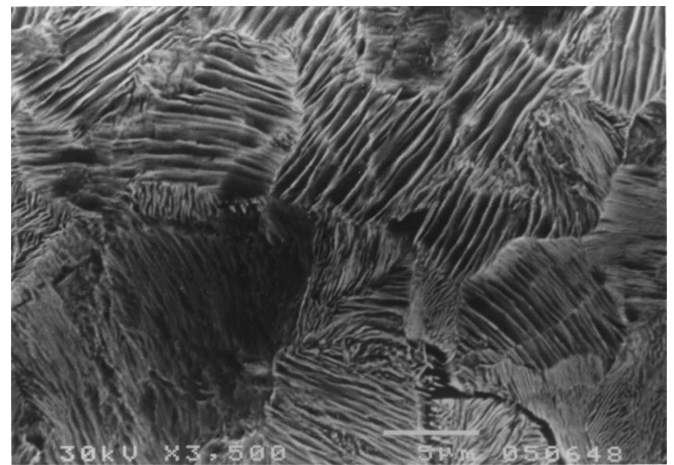


Fig. 8. Structure of the wire after patenting with the induction heating (12 kW) – specimen no. 1; (etched with Nital, magn. 3500 x)

As can be seen from Figs. 8 and 9, in the pearlitic-ferritic structure of the wire patented under the induction heating conditions for a coil induction power of 12 kW (Fig. 8) and 8

kW (Fig. 9), the distribution of cementite lamellas is correct and the packing is adequately dense, which should ensure the correct process of the wire deformation by drawing and the obtaining of finished wire characterized by an advantageous relation between the tensile strength R_m and the offset yield strength $R_{0.2}$.

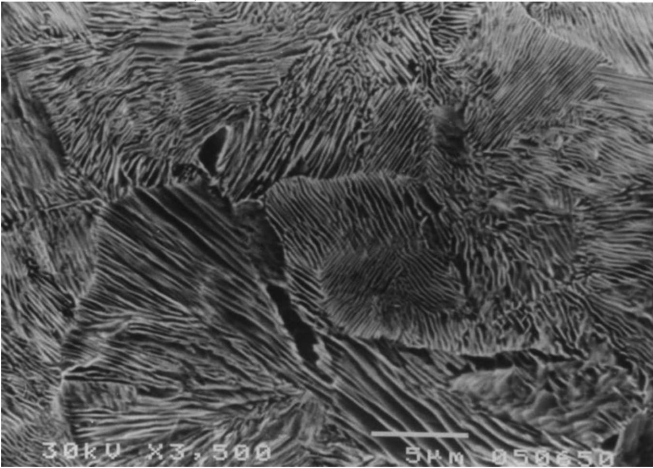


Fig. 9. Structure of wire after patenting with the induction heating (8kW) – specimen no. 2; (etched with Nital, magn. 3500 x)

4. Summary

As a result of the investigation carried out it has been concluded that carrying out the first stage of the patenting process using the induction heating yields wire with the correct mechanical properties and an advantageous plasticity reserve factor, when the adequately high coil induction power is applied.

The implementation of this technology is expected to provide the possibility of intensifying the wire patenting process, thus resulting also in the measurable economic benefits.

REFERENCES

- [1] Z. Muskalski, Analiza wpływu kierunku ciągnięcia drutów na ich wytrzymałość zmęczeniową i trwałość zmęczeniową lin stalowych (in Polish), Częstochowa 2004.
- [2] Z. Steininger, Obróbka cieplna i powierzchniowa drutów stalowych (in Polish), Katowice 1977.
- [3] H.A. Barnes, Journal of Non-Newtonian Fluid Mechanics **70**, 1-33 (1997).
- [4] J.G. Sevillano, Patterns in heavily deformed metals. Physica Scripta **49**, 405 (1993).
- [5] J. Łuksza, Elementy ciągarstwa (in Polish), Kraków 2001.