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Influence of Different Ecoquench Temperature on High Carbon Steel Wire Mechanical Properties

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Abstract:

Patenting heat treatment wires in the production of bead wire, spring wire and wire rope provide suitable microstructural properties for subsequent diameter reduction steps. The process of patenting in the fluidized bed, which is a faster and more environmentally friendly process than the conventional lead bath, is carried out in two stages: After heating to the austenitizing temperature, a thin perlite structure is obtained after cooling at the appropriate speeds in the fluid sand bed. Both high tensile strength and ductility can be achieved by suitable patenting conditions. The effect of fluid bed temperatures and cooling rate on the success of the process is of critical importance. In this study, mechanical properties (tensile, elongation, elongation ratio, torsion) and microstructure effects of different fluidized bed temperatures for wt. 0,83 % carbon wires at 3.5 mm diameter were investigated.

Keywords: High Carbon Steel Wires, Patenting Process, Fluidized Bed Temperature, Pearlite, Mechanical Properties

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1. Introduction

High strength steel wires are widely used in many industrial applications. Carbon steels (AISI 1045-1100) are preferred in the range of wt. 0,45 % to 1 C in these applications such as wire ropes, bead wire, tire cords prestressed concrete wire and spring wires. A special intermediate heat treatment is applied to increase the drawability of these wires. This heat treatment has two-stage and is called patenting process. The main goal in metallurgical aspects of the patenting process is to modify the microstructural properties of the steel wire to obtain the appropriate strength and ductility properties of the wire. In this direction, the steel wire is firstly heated to the austenitizing temperature (T>950 ˚C) to obtain homogeneous coarse austenite grains. Following this stage, it is desired to obtain fine pearlitic microstructure by controlled cooling process in molten lead bath or fluidized sand bed. Patenting operations in the molten lead bath are limited due to environmental reasons as well as workers' safety and health. Besides, molten lead patenting process is a highly expensive process as it consumes heavy energy in achieving the correct temperature in wires and desired lead bath temperature. Fluidbed (Ecoquench) patenting furnaces have an advantage of significantly higher heat-transfer and therefore faster wire speed, but have issues with atmosphere control and scale formation (Fig.1). Today, due to the increased wire production capacity, many wire manufacturers are more interested and preferred in the process of patenting fluidized bed. Patented process in the fluidized bed is more economic and environmentally friendly than molten lead bath, but also permits production at higher line speeds [1-6].

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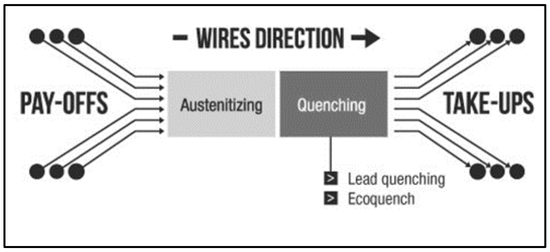

Figure 1. Schematic patenting process line (FIB)

Metallurgical aspect, patenting process is controlled by an isothermal transformation (TTT). At which time, temperature and transformation graphics are used to determine the pearlite transformation time and rate of the austenite phase structure in Fig.2a and b. The isothermal TTT diagram shows that it is therefore necessary to cool the wire from austenitisation temperature very fast to T<550 °C and then keep this temperature for a few seconds [1-4]. Many process parameters affect the cooling process in the fluidized bed. Among them, Ecoquench bed temperature, sand type, sand size distribution, sand density, fluid pressure are the most important ones. However, there is not enough literature on the effect of Ecoquench temperature on the mechanical properties of steel wires.

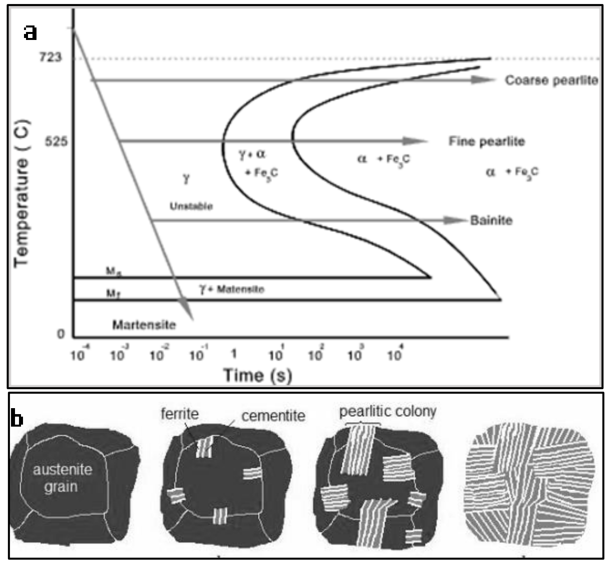

Figure 2. **a.** Patenting heat treatment on TTT diagrams **b.** fine pearlite structure

A lot of study on quality aspect of patented wire is reported but limited study has been carried out on quantative aspect in industrial set up. The fluidised bed patenting has been considered as an alternative effective

Table 1. Steel chemical composition

C %	Mn%	Si%	P%	S%	Cu%	Cr%	N%	Ni%	V%
0,83	0,59	0,22	0,014	0,017	0,015	0,034	0,005	0,016	0,001

Table 2. The reduction ratios and drawing speed in dry drawing process

Initial Diamater	**5,50** mm	**Mean reduction for each pass**	**20,23 %**
1. Pass	5,00 mm	**$A_{initial}$:**	23,75 mm^2
2. Pass	4,52 mm	**A_{final}:**	9,62 mm^2
3. Pass	3,92 mm	**Total reduction :**	59,50 %
4. Pass	3,50 mm	**Drawing Speed:**	140 m/min

Table 3. Patenting process parameters and technical specifications

Furnace -1	**Austenitizing furnace temperatures**				**Austenitizing furnace**	
Zone	**1**	**2**	**3**	**4**	Open fire furnace Natural gas fuel	
Temperature, ºC	1032	1010	990	960		
Pressure, cm water	54	37	12	10		
Furnace -2	**Ecoquench: Fluidized sand bed patenting tempearatures**				**Ecoquench**	
Zones	**1**	**2**	**3**	**4**	Sand type Sand size	Zr_2SiO_4 +150µm -250µm
Test-1 Temperature, ºC	235	287	399	401		
Test-2 Temperature, ºC	265	266	380	440	Fluidized bed pressure: 8 mbar	
Test-3 Temperature, ºC	297	309	371	415		

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method to molten lead bath as a controlled quenching. In this study, the effect of different Ecoquench furnace temperatures on the mechanical properties of the wires was investigated in detail.

2. Experimental Details

The steel material for the experimental study was Ø 5,5 mm wire from wt. 0,83 % C (Table 1). The wires were subjected to heat treatment in industrial conditions on the patenting production line. After passing from a patenting line the wires were subjected to a surface chemical treatment, ie. washing in water, pickling in HCl, by washing in a cold water and then phosphating. After the surface treatment, wire rod of the diameter Ø 5,5 mm was drawn on Ø 3,50 mm diameter wire. The reduction ratios and drawing speed in dry drawing process are given in Table 2.

Experimental work has been carried out on the industrial production line. The technical characteristics of the Ecoquench furnace and the temperatures used in the experiments are shown in Table 3. The Ecoquench oven consists of 4 different zone. Start and exit zone temperatures range from 235-450 ˚C.

The patented wire specimens were pulled to the universal tensile testing unit (Zwick 5 kN, strain rate: 0.006 sn^{-1}) in accordance with TSE EN ISO 6892-1 standard. Yield strength, tensile strength, yield/ tensile strength ratio, elongation ratios after the test were compared comparatively. Subsequently, fracture zones were observed in the electron microscope (SEM).

3. Results and Discussion

The cold drawing activates in the steel wire a strain hardening mechanism, so that it produces a clear improvement of mechanical properties obtained from a standard tensile test: both the yield strength ($\sigma_{0,2}$) and the ultimate tensile strength (σ_{max}) increase with cold drawing, while the elastic modulus (E) remains constant and the elongation (ductility) decreases with it. For steel wires, patenting heat treatment is a necessary for a higher total drawability. The desired high elongation ratio can be gained by obtaining suitable microstructural properties. Thin lamellar pearlite structure (sorbite phase) gives both high strength and ductility. The percentage of pearlitic microstructure developed in patenting process has direct influence on ultimate tensile strength, torsion strength and reduction in the area of patented wires. The research presented in Table 4, Fig.3 and Fig.4 shows that heat treatment parameters on the line to patenting steel wire significantly affect its mechanical properties. In addition, σ-Ɛ curves are shown below after wire drawing and heat treatment. The tensile strength values are increased depend on cold deformation and the elongation ratio values decreased. An increase in the elongation ratio is observed while the strength is partially lowered after the patenting heat treatment

Table 4. Mechanical properties of steel wires

Ø Diameter	**$\sigma_{0,2}$**	**$\sigma_{max.}$**	**$\sigma_{0,2}/\sigma_{max.}$**	**% Ɛ**		
Wire rod 5,5mm	720±20 MPa	1177±50MPa	0,62-0,65	6,9-7,2		
Result Values Ranges (for 9 test measurement)				**Min**	**Mean**	**Max**
Cold drawn wire 3,5mm	1195-1275	1565-1590	0,78-0,82	4	4,2	4,5
Patented wire 3,5mm	850-940	1275-1350	0,66-0,75	5,9	6,2	7,6
Cold drawn wire 1,2mm	1850-1920	2210-2250	0,88-0,92	2,4	2,6	2,8

In the tensile test, the length of the wire and the conical fracture shape are shown in the SEM images. When the fracture surfaces are examined, it is seen that the outer side is hard and the brittle (smooth) inner surface is ductile (rough) in Fig.4a, b and c. Conical-cap fracture surface characteristic shows the brittle surface of the wire surface and the ductility of the wire center.

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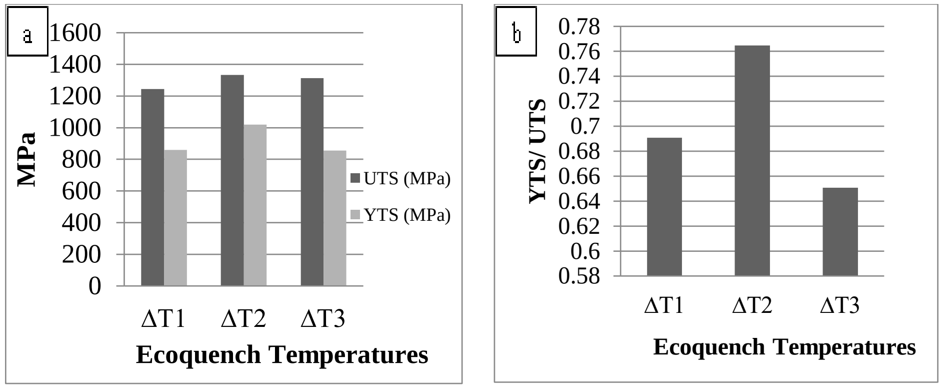

Figure 3. **a.** Change of tensile strength and yield strength **b.** Yield strength/ tensile strength ratio values after patenting at different ecoquench temperatures for 3,5 mm patented wires.

In the tensile test, the length of the wire and the conical fracture shape are shown in the SEM images. When the fracture surfaces are examined, it is seen that the outer side is hard and the brittle (smooth) inner surface is ductile (rough) in Fig.4a, b and c. Conical-cap fracture surface characteristic shows the brittle surface of the wire surface and the ductility of the wire center.

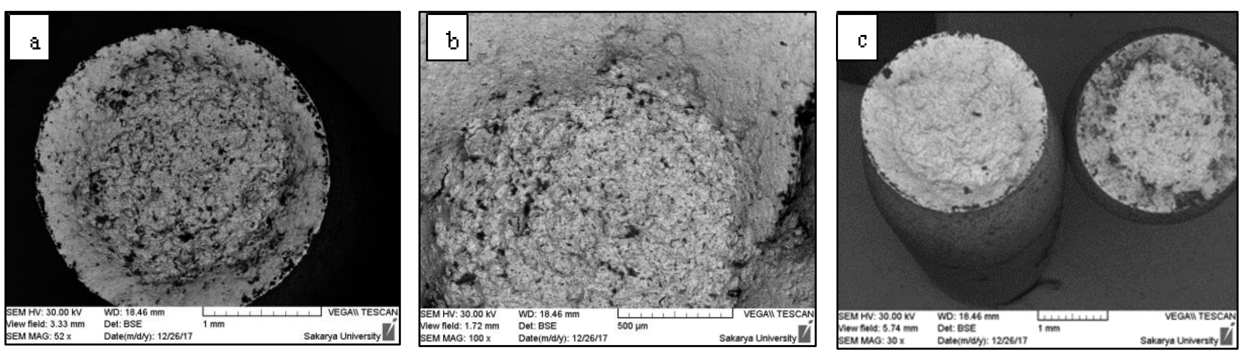

Figure 4. Fracture zones of patented steel wires after tensile test (3,5mm) **a.** SEM magnification of 50X **b.** SEM magnification of 100X **c.** SEM magnification of 30 X

4. Conclusion

From the experimental studies carried out, the following findings and conclusions have been drawn: The parameters which affect the quality and quantity of pearlitic microstructure in patenting process are bed temperature, transformation time and wire diameter. As a result of the patenting heat treatment, both the strength and the ductility are ensured in the steel wires. It has been found that the ductility properties are particularly influenced by the ecoquench temperature. The mechanical properties precisely controlled based on the fluid bed temperature. It is quite difficult to obtain the desired elongation values in the case of temperature fluctuations. In addition to the selection of sand type and sand size appropriate to the diameter and to the carbon content of steel wires, it is necessary to keep the fluid bed pressure constant and temperature changes controlled. The highest tensile strength obtained was at 1350 MPa and the highest elongation obtained was 7.1 % at test 2 (ΔT2:265-440 ˚C; 175 ˚C). In this context, in experiment 2, where the fluid bed temperature range results are the greatest, the targeted high mechanical properties are provided in the cooling conditions of the fluidized bed. The path position, diameter and carbon content of the wires passing through the furnace influence the mechanical properties. Appropriate drawing speeds must be determined for each wire during patenting.

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