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MICROSTRUCTURE EVALUATIONS IN PEARLITIC STEELS WIRES RESULTING FROM MODIFICATION OF THE INTEROPERATION ANNEALING PROCESS

Pearlitic steels containing from some 0.8 to 0.95% C belong to the group of unalloyed steels of the quality class destined for cold drawing or rolling. At the same time, the steels are characterised with particularly low share of non-metallic inclusions and limited contents of chromium and nickel, which extend the pearlite reaction time. The pearlitic steel in the annealed state has the highest strength in relation to other unalloyed steels, therefore she have found application mainly as wire rods for springs, wires for car tire reinforcement and cables. However one of the issues widely discussed in literature is cracking of pearlitic steel subjected to plastic working, caused by high brittleness of the lamellar precipitations of hard cementite. This issue is extremely important because it affects significantly reduce fatigue strength. The paper presents proposals to modify the process of interoperation annealing in order to eliminate this problem.

1. INTRODUCTION

Pearlite is an eutectoid mixture composed of ferrite and cementite plates, created as the result of pearlite reaction taking place after austenite cooling down slightly below the A1 temperature [1],[5]. The driving force of a pearlitic reaction is the difference in free energy between austenite and the ferrite and cementite mixture. Diffuse pearlite character of is related to the rearrangement of carbon atoms, which occurs through nucleation and nucleus growth. Pearlite nucleation runs heterogeneously, i.e. in the privileged way, at the cementite particles, ferrite plates, and in the homogeneous austenite, at grain boundaries of that phase [2],[3],[5]. The created pearlite colonies are spherical in shape, as the rate of new plates outbuilding and frontal growth are similar. As a result of carbon diffusion into the cementite plates, a diversification of the austenite chemical composition is taking place before the change front.

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The thickness of the cementite plates is seven times smaller than the ferrite plates. At constant temperature, thicknesses of each pearlite phase are almost constant and do not depend on grain size and austenite homogeneity, of which they are created [2],[3]. At relatively low degree of austenite overcooling, i.e. slightly below the eutectoid temperature, the transformation lasts very long, and carbon is able to diffuse for greater distances, thus the coarse-grain pearlite is being created. Lowering the transformation temperature shortens its time, carbon diffusion takes place at shorter distances, more thinner plates are created, and that is the fine-grain pearlite [14],[15]. Increasing the pearlite plate dispersion enhances its strength properties and causes rise in hardness.

Pearlitic steels containing from some 0.8 to 0.95% C belong to the group of unalloyed steels of the quality class destined for cold drawing or rolling [5],[8],[9]. At the same time, the steels are characterised with particularly low share of non-metallic inclusions and limited contents of chromium and nickel, which extend the pearlite reaction time. The pearlitic steel in the annealed state has the highest strength in relation to other unalloyed steels, therefore she have found application mainly as wire rods for springs, wires for car tire reinforcement and cables [13],[19].

However one of the issues widely discussed in literature is cracking of pearlitic steel subjected to plastic working [6],[11],[13],[16]. This issue is extremely important because it affects significantly reduce fatigue strength. The paper presents proposals to modify the process of interoperation annealing in order to eliminate this problem.

Modification of the interoperation annealing process will involve the hardening and tempering treatment, as the first stage of the interoperation heat treatment. The idea of modification was based at possibility of obtaining a steel of the sorbite or tempering troostite structure, which are a mixture of ferrite and dispersive cementite of high coagulation degree [1],[5],[17]. Structures obtained with such method as spherical in shape are to be featured by better plastic properties than lamellar structures, being created during the standard austenite diffusion transitions, and will eliminate the cracking problem in pearlitic steel subjected to cold working.

2. EXPERIMENTAL PROCEDURES

Subject of the researches was pearlitic steel of chemical composition (see Table 1) and mechanical properties according the PN-EN 10323:2005 (U) Standard. Samples for tests were prepared in the form of steel wires of diameters from 3.15mm to 0.8mm, obtained in the subsequent stages of standard cold working and simultaneously after the heat treatment involving hardening (in oil) and tempering within the 400ºC to 500ºC temperature range as the first stage of the cold drawing (see Table 2) [1],[18]. Microsections of the subsequent samples were prepared in the direction compatible with the plastic working, using the mechanical processes of grinding and polishing, as well as the chemical etching with 3% Mi1Fe.

For evaluation of the modification heat treatment process results in the plastically strained steel wires, the DM4000 Leica, light microscope was used. Observations of the pearlitic steel microstructures in the subsequent research stages and was conduct at magnifications within the 100× to 1000× range. Image recording will be performed by the DP71 Olympus digital camera coupled with the microscope, using the Spot Advanced and System Stream Enterprise software.

Table 1. Chemical composition of pearlitic steel according to the PN-EN 10323:2005 (U)

CHEMICAL ELEMENT	**C**	**Mn**	**Cr**	**Ni**	**Si**	**S / P**
[%]	0.83	0.4-0.6	<0.1	<0.15	<0.3	<0.025

Table 2. The sequence of samples investigated and documented within this article

NUMBER OF SAMPLE	**PROCEDURE OF REALIZATION**
No. 1	material in the state of delivering
No. 2	sample No. 1 after cold working
No. 3	sample No.1 after hardening and tempering treatment in 400ºC temperature
No. 4	sample No. 3 after cold working
No. 5	sample No.1 after hardening and tempering treatment in 500ºC temperature
No. 6	sample No. 5 after cold working

Observations of the pearlitic steel microstructures in the subsequent research stages was conduct also with the use of Scanning Electron Microscope Phenom G2 Pro, at magnifications from 2000× to 20000×. During the tests an accelerating voltage of 20 and 25kV will be applied. The observations are to be performed with the material contrast, using the SE detector.

Measurements of Vickers hardness were executed on transverse section of samples, about five imprints on one sample, according to the PN EN ISO 6507-1 Standard. Zwick 321 hardness tester was used, with the load 0.5kG and working in the time of 15s.

3. RESULTS AND DISCUSSION

The observation of the sample No. 1, considered to be of an origin diameter of 3.15mm, shown that this specimen is a typically pearlitic steel for drawing applications with 0.8% of carbon. Pearlite observed under the metallographic microscope at low magnifications is etching into grey colour (see Fig. 1), and at greater magnifications a clear lamellar structure appears, in which a hard, and hardly etching cementite lamellae protrudes over the soft ferrite (see Fig. 2). The rectangular shape of pearlite colonies indicates that colonies' growth took place at a stress state in all the surrounding volume.

Pearlitic steels belong to the group of unalloyed steels of the quality class destined for cold drawing or rolling, this steel has the highest strength in relation to other unalloyed steels, therefore she have found application mainly as wire rods for springs, wires for car tire reinforcement and cables [5],[9]. However one of the important technological problem is cracking of the finished products during the subsequent stages of cold working or even during the use them [6],[10],[20],[21].

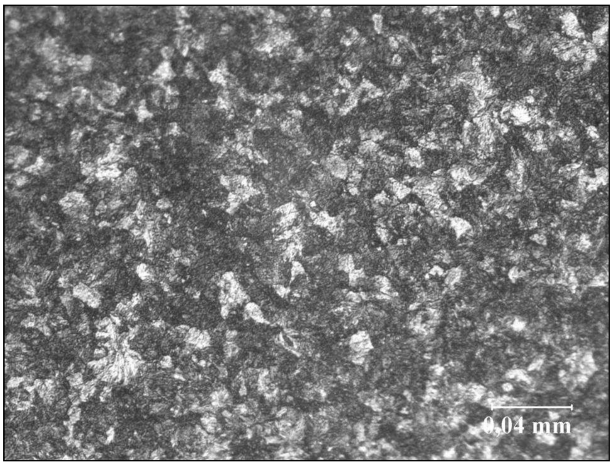

Fig. 1. Microstructure of perlite observed in a typically steel for drawing applications with 0.8% of carbon. Light microscopy, etching with 3% Mi1Fe

Fig. 2. Microstructure of the sample No. 1 observed by SEM, visible austenite grain boundaries and cementite lamellae protrudes over the soft ferrite

The microscopic observation of the sample No. 2, shown that this specimen was deformed about 60% compared to the base sample (see Fig. 3.). A highly deformation of structure observed in Fig. 4 leads to visible locally cracking of hard cementite lamellar (see Fig. 5.). This observation indicate that cracking of pearlitic steel subjected to plastic working, caused by high brittleness of the lamellar precipitations of hard cementite.

If the cracking of pearlitic steel caused by high brittleness of the lamellar cementite it means that the best way to eliminating this mentioned problem is changing of cementite morphology. Within this article, is shown the propose of modification the interoperation annealing process which involve the hardening and tempering treatment, as the first stage of the interoperation heat treatment. The idea of modification was based at possibility of obtaining a steel of the sorbite or tempering troostite structure, which are a mixture of ferrite and dispersive cementite of high coagulation degree [1],[5],[7],[13].

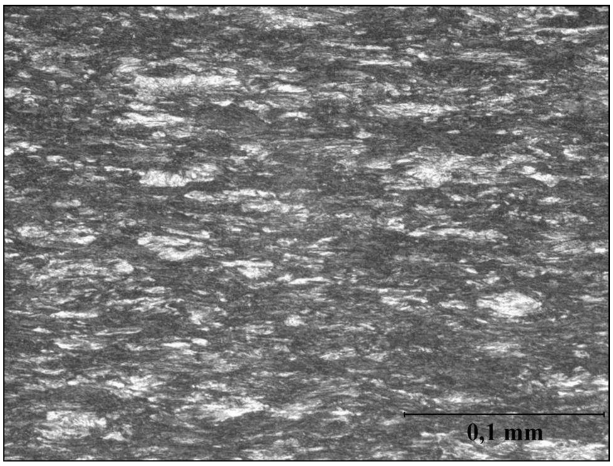

Fig. 3. Microstructure of sample No. 2, visible plastic deformation about 60%. Light microscopy, etching with 3% Mi1Fe

Fig. 4. Microstructure of the sample No. 2 observed by SEM, visible highly deformed pearlite colony

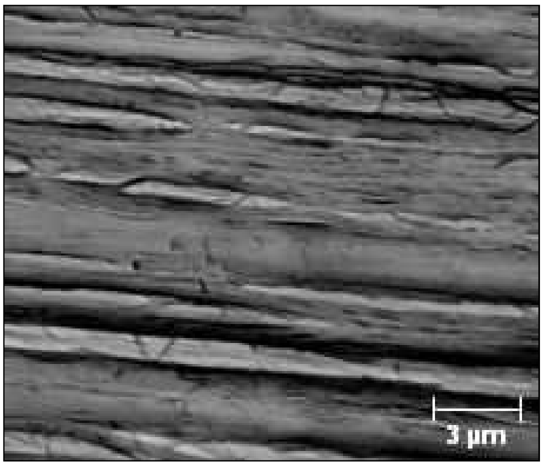

Fig. 5. Increase area of Fig. 4, visible broken cementite lamellae

Microscopic observation shown that the result of tempering with the 400°C temperature range a precipitation of carbon from martensite is taking place, creation of spherical disengagement of cementite, as well as decomposition of residual austenite into the carbon oversaturated ferrite and cementite (see Fig. 6 and 7). Specific volume drops and the created structure, which is a mixture of ferrite and cementite of very high dispersivity and certain degree of coagulation, is called troostite. As the heating progresses about 500°C, further cementite coagulation in the ferritic matrix takes place, consisting in dissolving fine particles and growth of big ones, which begin to assume the shape close to a sphere (see Fig. 8 and 9). After such tempering the structure is called sorbite.

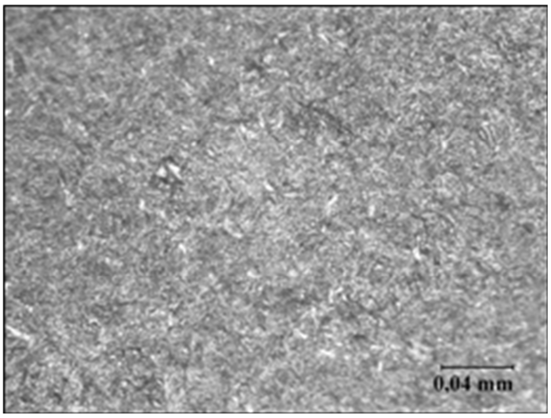

Fig. 6. Microstructure of troostite with small needles of bright martensite. Light microscopy, etching with 3% Mi1Fe

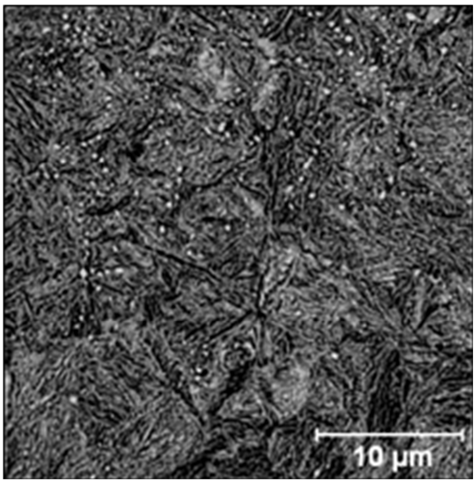

Fig. 7. Microstructure of the sample No. 3 observed by SEM, visible a mixture of martensite and cementite of high dispersivity of coagulation

The observation of samples No. 4 and 6, obtained in the subsequent stages of cold working preceded of the modification of heat treatment, shown clearly that structures spherical in shape are to be featured by better plastic properties than lamellar structures, being created during the standard austenite diffusion transitions (see Fig. 10 and 11). Spherical disengagement of cementite during plastic deformation underwent extension exclusively, there were no visible cracking or another types of decomposition, which means that this modification could eliminate the cracking problem in pearlitic steel subjected to cold working.

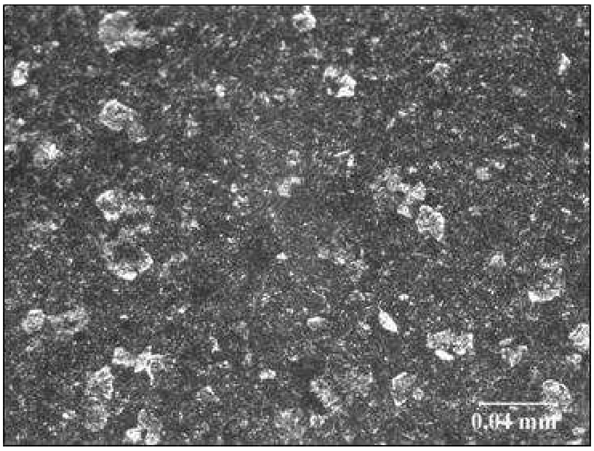

Fig. 8. Microstructure of sorbite. Light microscopy, etching with 3% Mi1Fe

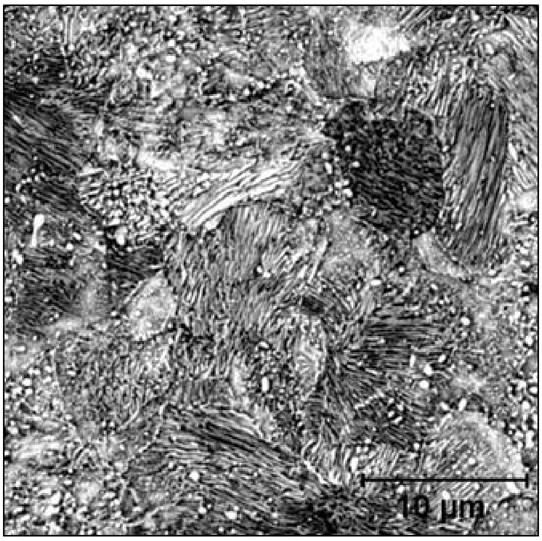

Fig. 9. Microstructure of the sample No. 5 observed by SEM, visible numerous spherical disengagement of cementite in the ferritic matrix

The consequence of the plastic treatment strain, is a change in almost all metal properties [4],[9],[12]. The changes manifest themselves, first of all, by consolidation of the metal, i.e. increase in its strength, yield point and hardness and, at the same time, by lowering the elongation and impact resistance.

The results of microhardness measurements confirmed that consequence of plastic deformation is visible increase of this parameter (see Table 3). The microhardness of base sample increase from 225HV to 416HV, however microhardness of modified sample increases to 590HV for 400°C and to 379HV for 500°C. Tempering with the 400°C temperature proceeded cold working leads to significant consolidation of the strained metal which could leads to the material destruction by de-cohesion. Modification of the technology with using higher temperature leads to obtainment the structure called sorbite which is characterised with better ductility.

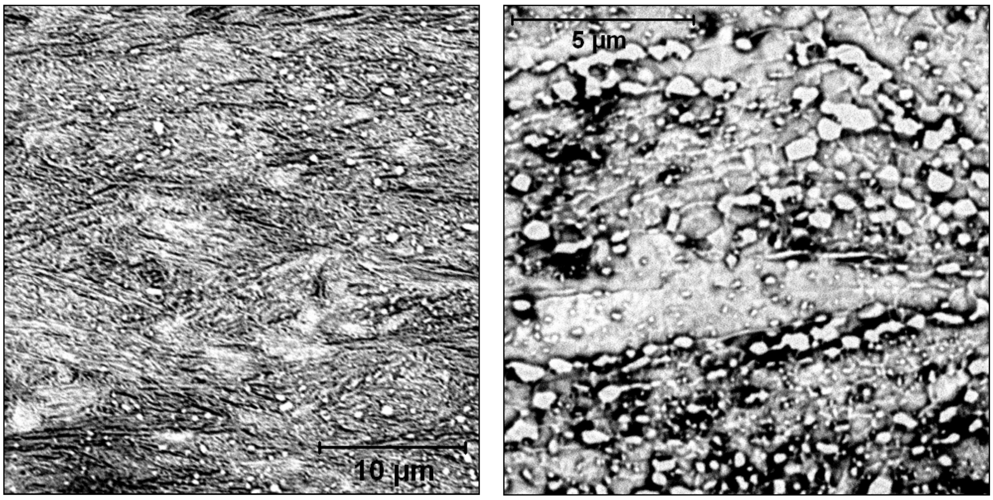

Fig. 10. Microstructure of the sample No. 4 after plastic deformation, visible elongated spherical disengagement of cementite. SEM

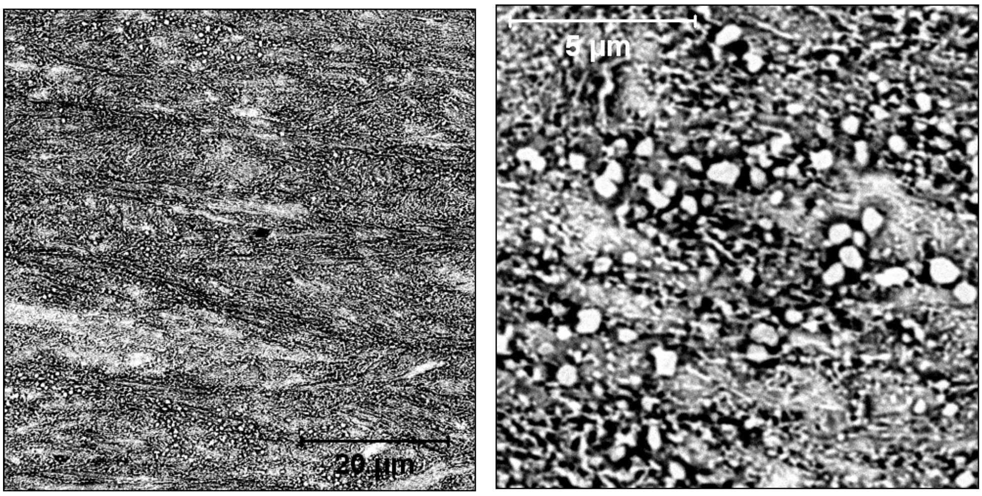

Fig. 11. Microstructure of the sample No. 6 observed by SEM, there were no visible cracking or another types of decomposition of cementite after plastic deformation

Table 3. The results of Vickers hardness measurements

NUMBER OF SAMPLE	**HARDNESS HV**					**AVERAGE HARDENSS HV1**
No. 1	212.5	235.1	220.6	218.6	238.4	**225.1**
No. 2	399.5	413.2	435.7	427.2	408.7	**416.9**
No. 3	487.1	483.9	465.9	478.2	483.3	**479.7**
No. 4	592.9	579.6	587.2	598.8	594.1	**590.5**
No. 5	300.5	305.9	314.1	322.7	310.7	**310.8**
No. 6	369.2	363.2	383.7	382.1	400.8	**379.8**

4. CONCLUSION

The main aim of the investigation presented in this article was modification of annealing process parameters applied during plastic treatment of pearlitic steel for patented wires. Modification involved the hardening and tempering treatment. as the first stage of the interoperation heat treatment. The idea of modification was based at possibility of obtaining a steel of better plastic properties than conventional structures and the same eliminate the cracking problem of this material subjected to cold working.

Results of microscopic observation show that tempering with the 400°C and 500°C temperature gave a possibility of obtaining a steel of the sorbite or tempering troostite structure. which are a mixture of ferrite and dispersive cementite of high coagulation degree. Structures obtained with these methods as spherical in shape had much better plastic properties than lamellar structures. being created during the standard austenite diffusion transitions. Spherical disengagement of cementite during plastic deformation underwent extension exclusively. there were no visible cracking or another types of decomposition. which means that this modification could eliminate the cracking problem in pearlitic steel subjected to cold working.

The results of microhardness measurements confirmed that tempering with the 400°C temperature proceeded cold working leads to visible increase of this parameter. Significant consolidation of the strained metal enables its further shaping by cold working. because it then leads to the material destruction caused by its de-cohesion.

The microhardness of sample tempering within the to 500ºC temperature range and cold drawing increase to 379 HV which is visible lower then base sample. obtaining with standard method. It means that modification of annealing process with using higher temperature leads to obtainment the structure characterised with high ductility. and could eliminate the cracking problem of pearlitic steel.

Pearlitic steels belong to the group of unalloyed steels of the quality class destined for cold drawing or rolling. At the same time. the steels are characterised with particularly low share of non-metallic inclusions and limited contents of chromium and nickel. which extend the pearlite reaction time. They have found application mainly as wire rods for springs. wires for tire reinforcement and cables. Explanation of the cracking mechanism and elaborating heat treatment procedures for pearlitic steel thus opens new application fields for those materials and new technologies of their production.

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