The effectiveness of spheroidization pearlitic steel with regard to the degree of plastic deformation

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Abstract: *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, they find application mainly as wires used for reinforcement of tires, hoses or rope production. However this group of steels characterized low machinability, as a consequence of presence hard plates of cementite, the intervention ameliorative this property is spheroidizing annealing. The object of the tests presented in paper was wires of pearlitic steel obtained after the successive stages of cold plastic working. The aim of the tests was to show that the condition of the material and mainly degree of plastic deformation have a clearly influence on the effectiveness of pearlitic steel spheroidization*.

Keywords: *Pearlitic steel, annealing, cementite*

1. Introduction

Pearlite is an eutectoid mixture composed of ferrite and cementite plates, created as the result of perlite reaction taking place after austenite cooling down slightly below the A_1 temperature [1, 2]. The driving force of a pearlitic reaction is the difference in free energy between austenite and the ferrite and cementite mixture. Pearlitic reaction is a diffusion type transformation, related to rearrangement of carbon atoms, taking place by 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. The created pearlite colonies are spherical in shape, as the rate of new plates outbuilding and frontal growth are similar [2, 3]. As a result of carbon diffusion into the cementite plates, a diversification of the austenite chemical composition is taking place before the change front.

Thickness of cementite plates is sevenfold smaller from that of 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 [1-3]. 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, thinner plates are created, and that is the fine-grain perlite. Increasing the pearlite plate dispersion enhances its strength properties and causes rise in hardness [1-3].

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 [3, 4]. The perlitic steel in the annealed state has the highest strength in relation to other unalloyed steels, therefore she have found application mainly as wires used for reinforcement of tires (PN-EN 10323:2005 (U)), hoses (PN-EN 10324:2006), or rope production (PN-EN 10264-1:2005) [3, 4].

However the pearlitic steels characterized low machinability, as a consequence of presence hard plates of cementite, the intervention ameliorative this property is popular heat treatment called spheroidizing annealing [6-8]. Spheroidization consists in the transformation of the lamellar cementite precipitates into the globular form and it is conducted by heating the steel to a temperature close to A_{C1}, holding it at this temperature, very slow cooling it to a temperature of about 600°C and then arbitrarily cooling it down to the ambient temperature [9, 10]. The nucleation of spheroids takes place as a result of the fragmentation of the lamellar precipitates due to the structural defects, concentrations of admixtures or impurities and pile-ups of lattice defects present in the matrix [6, 11-13]. This means that the additional factors contributing to the effectiveness of coagulation are: the fineness of the structure, the metallurgical purity and the most important degree of plastic deformation.

2. Materials and methods

The aim of the tests was to show that the condition of the material and mainly degree of plastic deformation have a clearly influence on the effectiveness of pearlitic steel spheroidization.

Tab. 1. Chemical composition of pearlitic steel acc. to PN-EN 10323:2005 (U).

CHEMICAL COMPOSITION	C	Mn	Cr	Ni	Si	S / P
wt.%	0,83	0,5	0,1	0,15	0,3	0,025

The object of the tests was pearlitic steel whose chemical composition (Tab. 1) and mechanical properties were consistent with PN-EN 10323:2005 (U). Specimens for the tests were prepared in the form of wires with different diameters, ranging from 3.15 mm to 0.5 mm, obtained after the successive stages of cold working and heat treatment which included heating to the temperature about 680°C, holding it at this temperature for one hour, very slow cooling it to the temperature about 600°C and then cooling in the air to the ambient temperature (Tab. 2).

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

SAMPLE	STATE OF MATERIAL
No. 1	material in as supplied condition with diameter 3.15 mm
No. 2	sample No. 1 after plastic working from 3.15 mm to 2.0 mm
No. 3	sample No. 2 after spheroidizing annealing
No. 4	sample No. 1 after plastic working from 3.15 mm to 1.0 mm
No. 5	sample No. 4 after spheroidizing annealing
No. 6	sample No. 1 after plastic working from 3.15 mm to 0.5 mm
No. 7	sample No. 6 after spheroidizing annealing

Observations of the pearlitic steel microstructures in the subsequent research stages was conduct with the use of Scanning Electron Microscope Phenom G2 Pro, at magnifications from 1000× to 20000×. During the tests an accelerating voltage of 20 and 25 kV was applied. The observations were to be performed with the material contrast, using the SE detector. The microsections of the specimens were prepared in the direction consistent with the direction of the plastic working, by grinding, mechanical polishing and chemical etching with 3% Mi1Fe.

Measurements of Vickers microhardness were executed on transverse section of samples, about five imprints on one sample, according to the PN-EN ISO 6507-2:1999 MMT-X3 micorhardness tester was used, with the load 500 g and working in the time of 15s.

3. Results

The first stage of the studies was microscopic observation of the material in as supplied condition, in the form of wires with diameter 3.15 mm, obtained as a result of the previous hot working. The microobservation of this sample shown that this is a typically pearlitic steel for drawing applications with 0.8% of carbon. Pearlite observed under the scanning electron microscope at greater magnifications as a clear lamellar structure appears, in which a hard, and hardly etching cementite lamellae protrudes over the soft ferrite (see Fig. 1). Length scale of observed structures in this specimen ware: perlite colony 1 µm to 3 µm, cementite lamellae 50 nm to 100 nm and cementite plates about 10 nm. The rectangular shape of pearlite colonies indicates that colonies' growth took place at a stress state in all the surrounding volume.

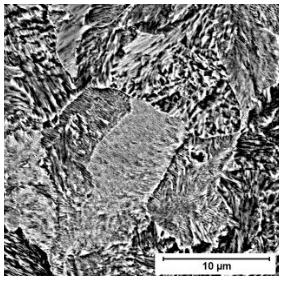

Fig. 1. Microstructure of sample No. 1 observed by SEM, visible austenite grain boundaries and cementite lamellae protrudes over the soft ferrite.

The microscopic observation of the others samples like No. 2, 4 and 6 with diameter from 2.0 mm to 0.5 mm, obtained after the successive stages of cold working, shown that this specimens had different degree of plastic deformation. Material of sample No. 2 was deformed about 36%, No. 4 about 68% and sample No. 6 about 84% compared to the base sample (see Fig. 2, 3 and 4). Length scale of observed structures in these specimens ware: cementite lamellae are about 50-80 nm, the enclosed ferrite layer has a thickness of about 30 nm to 45 nm.

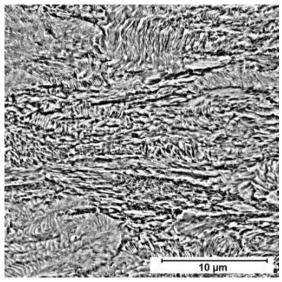

Fig.2. Microstructure of the sample No. 2, visible low deformed pearlite colony. SEM

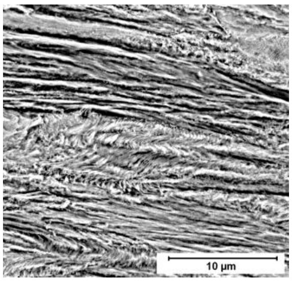

Fig.3. Microstructure of sample No. 4, visible plastic deformation about 70%. SEM

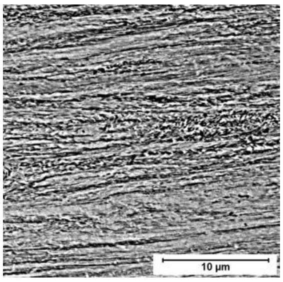

Fig.4. . Microstructure of the sample No. 6 observed by SEM, visible highly deformed pearlite colony.

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 the highest strength in relation to other unalloyed steels [3, 4]. They have found application mainly as wire rods for springs and wires for tire reinforcement. However the pearlitic steels characterized low machinability, as a consequence of presence hard plates of cementite [6]. The intervention ameliorative this property is heat treatment called spheroidizing annealing, which consists in the transformation of the lamellar cementite precipitates into the globular form. However the literature data clearly show that on the effectiveness of coagulation contribute the additional factors like: the fineness of the structure, the metallurgical purity and the most important degree of plastic deformation [8-11]. Therefore it seems necessary to individually analyze the range for cementite coagulation in the particular material states.

Microscopic observations of the deformed samples after spheroidizing annealing clearly show the subjection between degree of plastic deformation and degree of cementite coagulation. Sample No. 3 which was deformed about 36% characterized the smallest sferoidization degree about 45%, sample No. 5, with 68% plastic deformation had 50% degree of coagulation and simultaneously the highest degree of cementite coagulation had sample No. 7 with previous plastic deformation about 84% (see Fig. 5-7 and Table 3). It proves the theory that the degree of plastic deformation is important factor contributing to the effectiveness of steel coagulation .

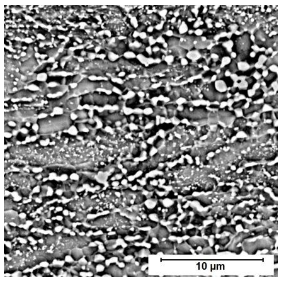

Fig.5. Microstructure of the sample No. 3 after spheroidizing annealing. SEM.

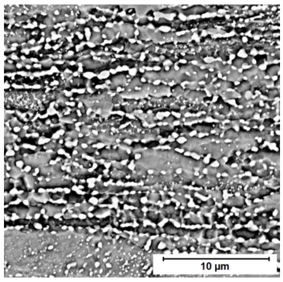

Fig.6. Material of sample with diameter 1 mm after sferoidization, visible high coagulation of peariltic structure. SEM

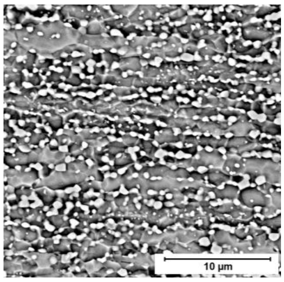

Fig.7. Microstructure of the sample No. 7 observed by SEM, visible the higher degree of cmentite coagulation. SEM

Tab. 3. Results of measurements of tested samples spheroidization degree.

SPECIMEN	SPHEROIDIZATION DEGREE [%]		
No. 3	44,71	42,76	49,19
No. 5	49,85	50,11	50,72
No. 7	50,91	52,23	51,09

Microscopic examinations of the material structure can only show correctness of the selected parameters of heat treatment. In order to get a full picture of the processes one should be analyze the mechanical properties of the tested specimens. In industrial practice the proper matching of annealing is determined mainly by measuring of the material hardness [2, 5]. Such measurements are easy to perform and do not require any special preparation of the specimens. For this reason hardness measurement by the Vickers method was used.

The literature data clearly show that that the globular structures of cementite characterized by much lower hardness than the lamellar structures, therefore it is possible to expect, that if the degree of cementite coagulation will be larger the hardness of material will be smaller [1, 3]. The confirmation of presented below theory can be clearly found in the results of microhardness measurements. The hardness of the sample No. 1 with typical pearlitic structure amount to 326 HV, however the hardness of the samples after heat treatment was in the range of 229-276 HV (see table 4). At the same time it was found that the hardness of the material is this smaller when the degree of cementite coagulation was higher.

Tab. 4. Results of material microhardness measurements for tested samples.

SPECIMEN	HARDNESS HV					AVERAGE HARDNESS
No. 1	332	312	333	318	338	**326**
No. 3	274	278	282	272	275	**276**
No. 5	217	229	256	239	250	**238**
No. 7	229	218	233	240	227	**229**

5. Conclusions

Pearlitic steels, containing from about 0.8 to 0.95% of C, 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 hoses, wires for car tire reinforcement and cables [1-4]. However this group of steels characterized low machinability, as a consequence of presence hard plates of cementite [6-8]. The intervention ameliorative this property is heat treatment called spheroidizing annealing, which consists in the transformation of the lamellar cementite precipitates into the globular form [9, 10].

The object of the tests presented in paper was wires of pearlitic steel obtained after the successive stages of cold plastic working, characterized with different degree of plastic deformation. The results presented in this paper show that the condition of the material and mainly degree of plastic deformation have a clearly influence on the effectiveness of pearlitic steel spheroidization.

Microscopic observations of the deformed samples after spheroidizing annealing clearly show the subjection between degree of plastic deformation and degree of cementite coagulation. Sample which was deformed only about 36% characterized the smallest sferoidization degree about 45%, simultaneously the highest degree of cementite coagulation had sample with the highest previous plastic deformation about 84%.

The confirmation of this theory can be clearly found in the results of microhardness measurements. The hardness of the sample No. 1 with typical pearlitic structure amount to 326 HV, however the hardness of the samples after heat treatment was in the range of 229-276 HV. At the same time it was found that the hardness of the material is this smaller when the degree of cementite coagulation was higher. This due to the fact that the globular structures of cementite characterized by much lower hardness than the lamellar structures, therefore if the degree of cementite coagulation is larger the hardness of material is smaller.

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