

Degradation Structures of the Steels Applied in Energetics

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Currently, it is in the power industry exerted the pressure in terms of environmental impact and economics. That means requirements focussed on the development of high efficiency and low emission systems. Both of these requirements leads to the increasing of the thermal efficiency of a power plant and that means also increasing of the working temperatures. In the future, it will be necessary to develop materials that can withstand these demanding conditions and requirements. Strength of steel used at high temperatures is one of the properties which affect the life time of the power equipment. These properties strongly depend on microstructure of material. However, useful initial microstructures are unstable in service conditions. The changes come gradually at temperature-dependent rate through processes of thermal degradation. Many of these processes are caused by changes in the carbide structure of the steels and other phase transformations. This contribution deals with the degradation structures of the steels applied in energetics.

Keywords: Degradation, Steels, Energetics, Microstructure, Carbides

1 Introduction

Energetics is currently one of the key areas of social-wide development. Energetics requirements for applied steels are complicated by the need to resist not only high temperatures and pressures but also often aggressive environments. The phenomenon of creep is applied over the long-term exposure of steels at high temperatures and pressures.

Due to the fact that most of the heat-resistant steels are operated for decades, it is necessary for safety reasons, to realize a material inspection at certain regular time periods and to find out the real structural and mechanical properties. The residual creep life, which is called residual life in the energetic industry, is identified on the basis of the experimentally determined values. An accurate estimate of the residual lifetime allows to plan the most economical unavailability time of the power equipment or the advance timing of the components exchange that are already in critical state.

The necessity of material inspection realization is related to the fact that fluctuation of temperatures occur very often in operation and, in consequence of this, the material properties change differently than expected.

Structural changes, which occur in steels, are legally accompanied by changes in their original mechanical, chemical and physical properties and we are talking about degradation processes.

Specific is the degradation of steels due to radiation irradiation occurring in nuclear power plants - radiation embrittlement. The explanation of this phenomenon, in a simplified way, consists of two concurrently ongoing processes.

- During passage of neutrons through the steel occurs by the influence of elastic collisions with Fe atoms to the displacement of some atoms from the lattice node points. The energy required for Fe atom displacement from the lattice node point is ca. 25 eV, but the energy of the flying

neutrons is much higher than ca. 2 MeV. Consequently, there are vacancies in the atomic displacement places that cluster and create the crack nucleus [1]. Displaced atoms are in non-equilibrium lattice positions and form Frenkel pairs (Fig. 1).

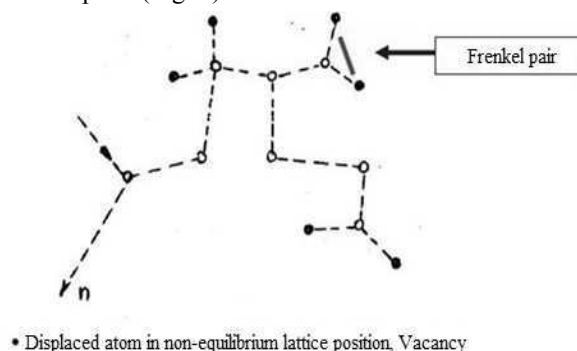


Fig. 1 Frenkel pairs creation scheme [1]

- During passage of neutrons occurs also to the nuclear reactions – transmutation, whose product is helium, which is not soluble in the steel and it settled at the grain boundaries and initiates the intercrystalline cracking.

The contribution is focused on the presentation and explanation of some steel structures arising from degradation processes.

2 Degradation (anomalous) structures of steels

2.1 Delta ferrite

With the presence of δ ferrite in the structure of low-carbon martensitic anticorrosive steels due to degradation processes it occurs to the significant increase of the transit temperature and the change of failure mechanism (ductile - brittle). The character of the structure with different amount of degradation is shown in Figure 2 [2-4].

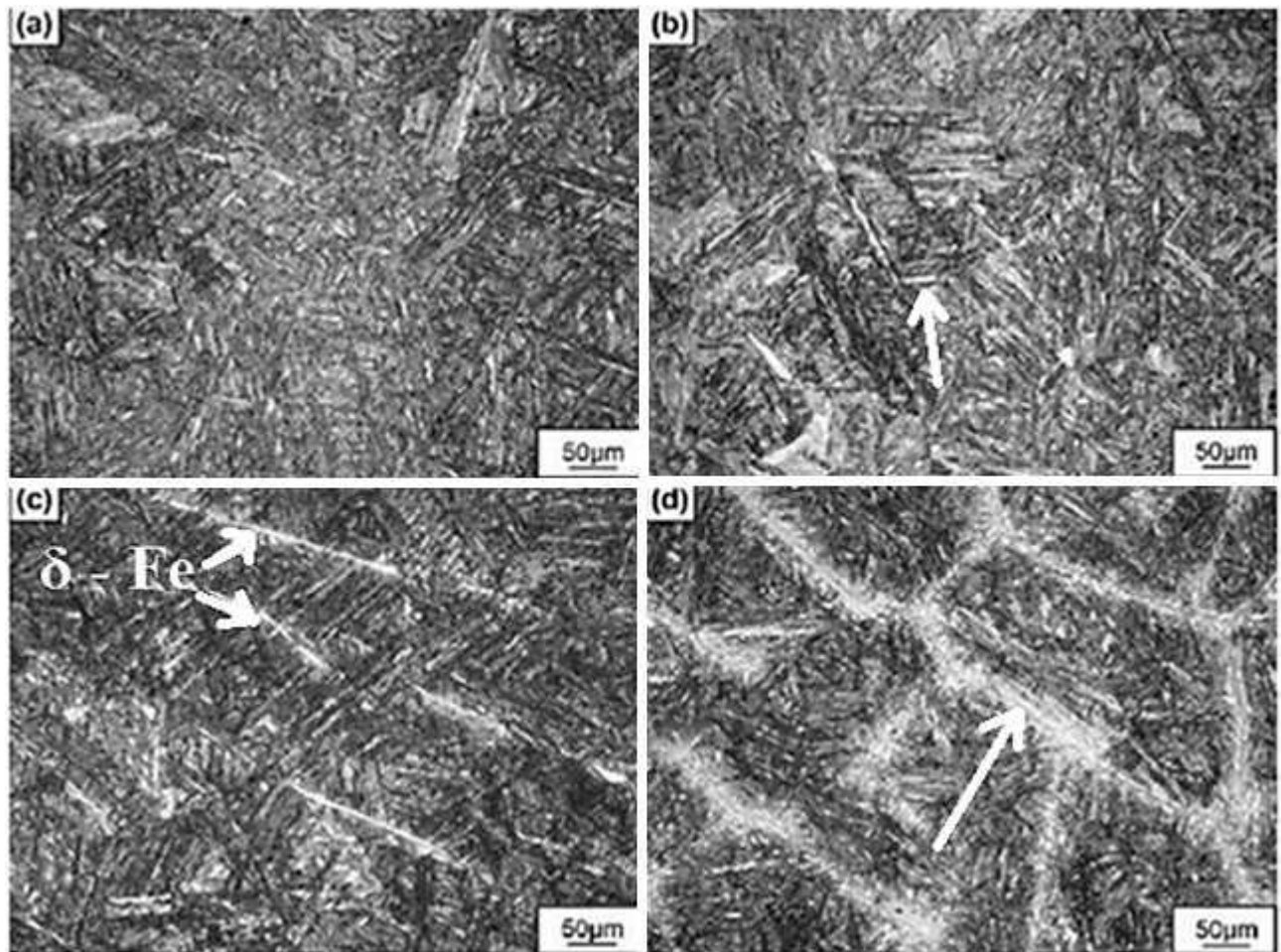


Fig. 2 The stages of the low-carbon martensitic anticorrosive steel structure degradation (a) tempered martensite, (b) elementary stage of degradation, crystallographically oriented thin needles of δ ferrite in the tempered martensite matrix, (c) advanced degradation stage, crystallographically oriented coarse needles in the tempered martensite matrix, (d) final stage of degradation, line network of δ ferrite along the elementary austenitic grain boundaries

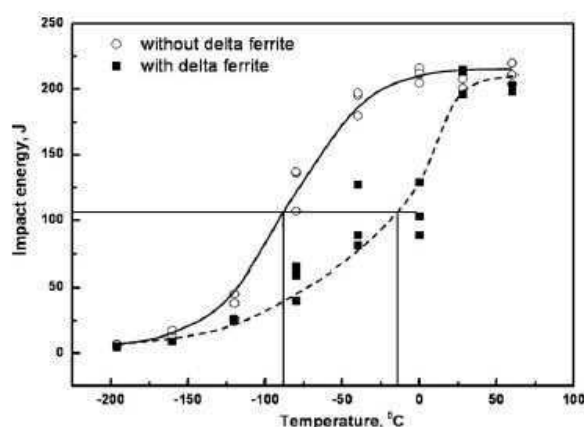


Fig. 3 The effect of the δ ferrite on the impact resistance [2]

From the point of view of fractography, the change of failure mechanism due to the presence of δ ferrite with the K8 lattice is related with the initiation of cracks by the brittle failure dislocation mechanism with the creation of

a critical size crack.

The effect of the δ ferrite on the impact resistance of the anticorrosion low-carbon martensitic steel 13Cr4Ni with a significant shift of the transit temperature to the plus thermal zones is shown in Figure 3.

Analogous negative effect of the δ ferrite presence in the structure is also in the welded joint zone of some ferritic-pearlitic steels applied in the energetics as well as in the case of austenitic anticorrosive steels [3].

2.2 Degradation of the lamellar pearlite

Steels applied in the energetics for example for steam lines are exposed to overheated steam temperatures ca. 540°C and a pressure ca. 10 MPa for several years. Cr-Mo-V steel 15 128 (ČSN 41 5128, DIN 14MoV63, W. Nr. 1.7715) is applied for this purpose in the Czech Republic. The pipes are supplied after normalization at temperatures 960-990°C and tempering at temperatures of 670-730°C. The minimum value of the impact resistance KCV is 35 J.cm⁻² at 18°C. The steel structure in the delivered state is ferritic – pearlitic with fine lamellar pearlite and excluded carbides in the ferrite matrix, Figure 4.

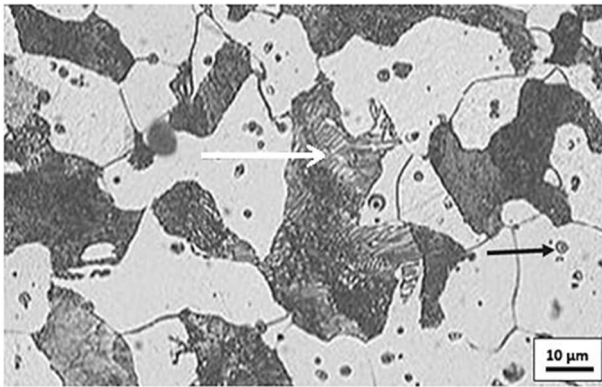


Fig. 4 15 128 steel structure character, initial state

The character of the degraded structure with globular carbide particles of the initially lamellar perlite and the excluded carbides at the grain boundaries after 198.217 hours is documented in Figure 5, the detail of the globular carbides is shown in Figure 6. It occurred simultaneously to the following degradation structural changes during the exploitation of the pipeline:

- the change of the initial lamellar pearlite to globulitic,
- the redistribution of carbide alloying elements (Cr, Mo, V) to the grain boundaries and thereby to its attenuation.



Fig. 5 Degradation structure character of the 15 128 steel after 198.217 hours

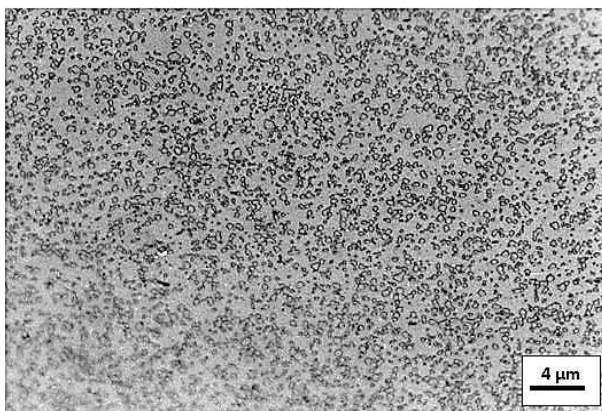


Fig. 6 Detail of globular carbides

The accompanying indicator of degradation structural changes are changes in mechanical properties and the change of the transit temperature. Figure 7 shows the

transit curve of the steel 15 128 after 198.217 hours of exposure. For the $KCV = 35 \text{ J.cm}^{-1}$ criterion, the displacement of the transit temperature was determined from the original temperature 18°C to 27°C .

Low KCV values in the temperature interval from 0 to 25°C are unacceptable from the view of the unavailability time and restarting to the operating value of the temperatures and pressures. If these values are low, it may occur to the rupture of the pipeline at the restart. Steel has become "brittle" due to degradation structural processes.

Steam piping line after 198.217 hours, $T = 540^\circ\text{C}$, $p = 9.8 \text{ MPa}$
Steel: 15 128 (0.15% C, 0.45% Mn, 0.25% Si, 0.64% Cr, 0.58% Mo, 0.31% V)

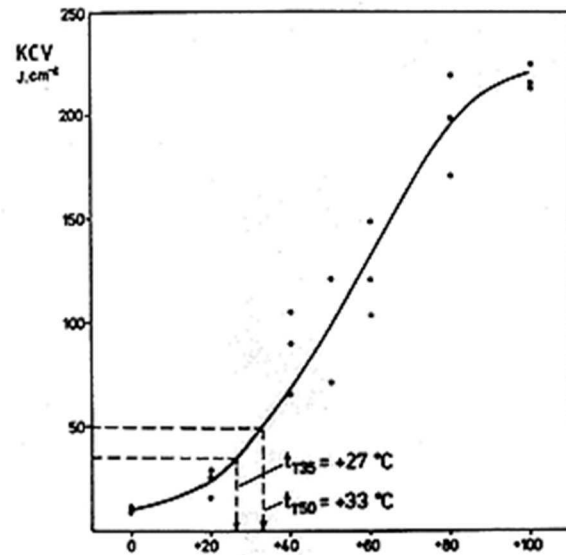


Fig. 7 Steel 15 128 transit curve after 198.217 hour exploitation

The cleavable character of the sample transcrystalline brittle fracture after the impact resistance test at the temperature 0°C is documented at Figure 8.

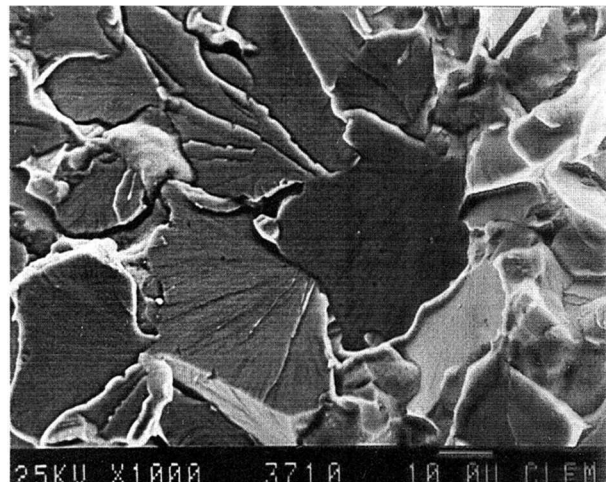


Fig. 8 Transcrystalline brittle failure of the sample at the temperature 0°C

The analysis results of the structure degradation processes and thus of the mechanical properties showed that the objective steam pipeline is necessary to replace during the course of one year [5-7].

2.3 Degradation by transformation of the original structure

The boiler overheaters, in whose construction are applied steels 15 111, are also a part of the heat energetic equipment. They are supplied in state after normalization at temperatures 960 - 990°C and tempering at temperatures 650 - 730°C. If in the exploitation process of this pipelines occur to the temperature overrange above the A_{c3} temperature of this steel, the following cooling from this temperature causes bainitic transformation, degrading the original structure. The effect of this transformation is the significant reduction of the steel plastic properties and creation of the surface cracks. Figure 9 presents the original structure, Figure 10 shows the structure after bainitic transformation - upper bainite. The next Figure 11 documents the detail of upper bainite structure and on the Figure 12 are surface cracks incurred in the consequence of the initial ferritic-pearlitic structure degradation to the upper bainite [8, 9].



Fig. 9 15 111 steel structure character, initial state



Fig. 10 15 111 steel degraded structure character, upper bainite



Fig. 11 Detail of the needle-shaped upper bainite character

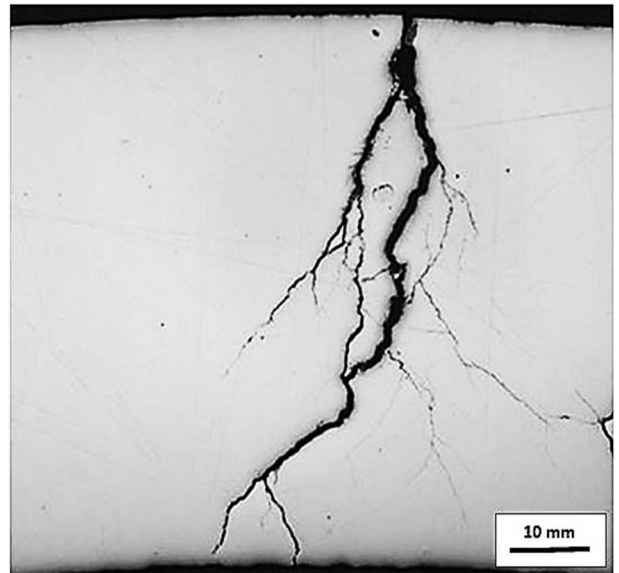


Fig. 12 Surface cracks on the 15 111 steel pipe

2.4 Degradation of the martensitic refractory steels properties with the excluding of the carbides along the initial austenitic grain boundaries

Martensitic refractory Cr steels are applied in power equipment in those parts where high values of the R_{mT} creep strength are required, for example steel 17 119 where $R_{mT}/600/100.000 = 100$ MPa [4]. The 17 119 steel pipe structure character in the initial, supplied state is shown in the Figures 13 and 14. The structural degradation form of this steel is exclusion of $Cr_{23}C_6$ carbides along the initial austenitic grain boundaries, Figure 15.

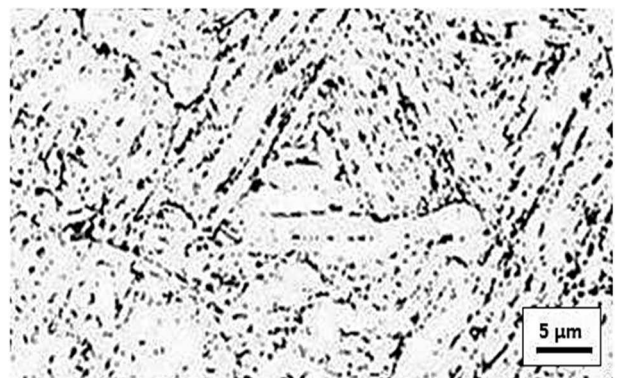


Fig. 13 17 119 steel lamellar martensitic structure

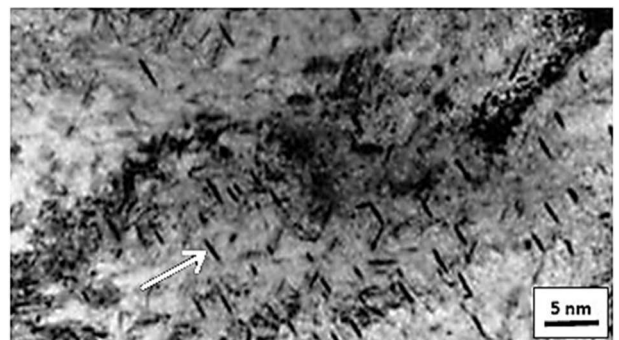


Fig. 14 Crystallographically oriented carbides in 17 119 steel martensitic plates

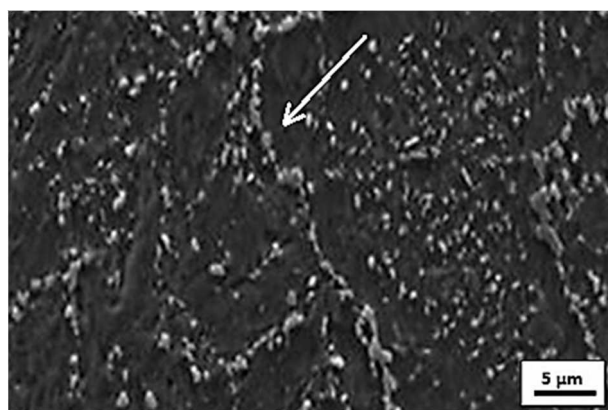


Fig. 15 Excluded carbides $Cr_{23}C_6$ along the initial austenitic grain boundaries of the steel 17 119

3 Conclusions

This contribution presents various mechanisms of structure degradation and the associated changes in the mechanical properties of steels applied in power plants. The necessity of regular inspections of the material state either "in situ" or by appropriate sampling of the given exposed locations and their subsequent analysis by the modern instrumentation also follows from the above mentioned facts.

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