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Electron microscopy investigation of the Cr–Mo–V cast steel

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ABSTRACT

Purpose: Investigation of low alloy Cr–Mo–V cast steel after long – term operation and regenerative heat treatment.

Design/methodology/approach: Micro structural investigations were carried out using transmission electron microscopy.

Findings: The microstructure and carbide types after long – term operation and after regenerative heat treatment (including bainitic hardening with high tempering temperature) of Cr–Mo–V cast steel have been presented.

Practical implications: : has been shown here is the influence of long term operation and regenerative heat treatment on the structure of Cr–Mo–V cast steel.

Originality/value: The paper presents influence of regenerative heat treatment – bainitic hardening with tempering – on the structure of G21CrMoV4 – 6 (L21HMF) cast steel after long - term operation.

Keywords: Metallic alloys; Electron microscopy; Microstructure

MATERIALS

1. Introduction

Changes in the microstructure of long-term serviced steels and cast steels at elevated temperatures cause decrease of their plastic properties, especially impact energy [1-6]. However, contrary to long-term serviced steels, decrease of impact energy in the case of steel casts does not allow for the possibility of their further safe operation.

Extension of service time of cast steels with structure degraded by long-term operation is obtained through the process of casts revitalization. The revitalization includes among other things: repair of fractures through welding and regenerative heat treatment. The purpose of regenerative heat treatment is to obtain "new", undegraded structure which would enable restoring of plastic properties demanded by the norm [7-11]. Self-study has proved that bainitic structure in an initial condition ensures optimum combination of high mechanical properties and high impact energy [10-12].

The paper presents results of research on microstructure of G21CrMoV4 – 6 (L21HMF) cast steel by means of transmission electron microscope (TEM). The microstructural research was carried out in the cast steel after long-term service as well as after regenerative heat treatment simulated in laboratory conditions.

2. Investigated material

The material of research was G21CrMoV4 – 6 (L21HMF) low alloy cast steel taken from the internal turbine frame, serviced for over 186 000 hours at the temperature of 540 ^{o}C and the pressure of 13.5MPa. Chemical composition of the investigated cast steel is given in Table 1.

Table1.
Chemical composition of the investigated cast steel (wt.%)

C	Mn	Si	P	S	Cr	Mo	V
0.19	0.74	0.30	0.017	0.014	1.05	0.56	0.28

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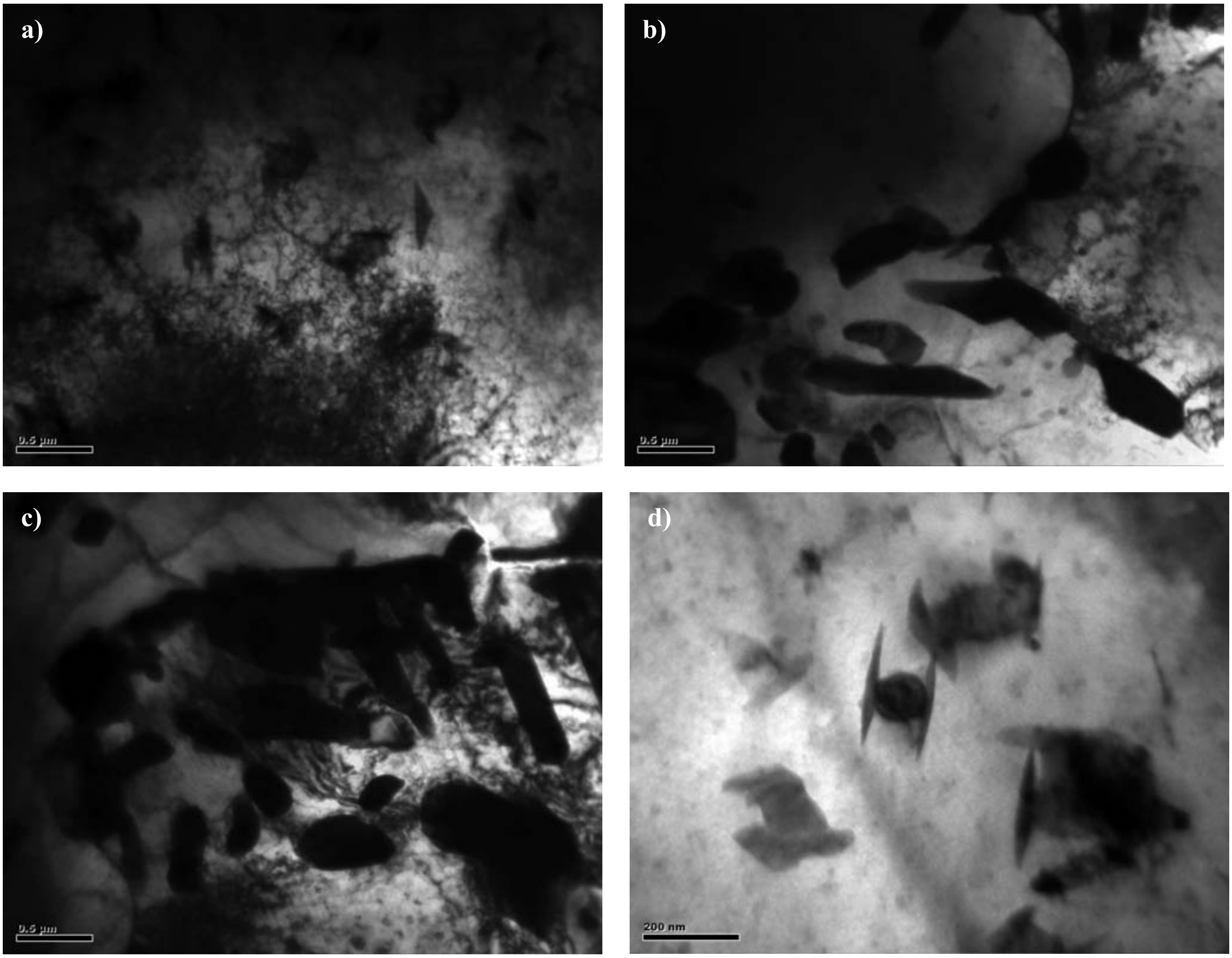

Fig. 1. Microstructure of Cr – Mo – V cast steel after long-term operation, TEM, thin foil

Heat treatment of the investigated cast steel after service consisted in bainitic hardening and high-temperature tempering – in order to obtain the structure of high-tempered bainite [8, 11].

Microstructural research was performed by means of transmission electron microscope of CM20 TWIN Philips model with the accelerating voltage of 200kV, using thin foils. Identification of precipitates was made by means of selective micro diffraction on thin foils as well as on carbon extraction replicas.

3. Microstructural characterization

3.1. After long – term operation

Investigated Cr – Mo – V cast steel after long-term operation was characterized by degraded ferritic – pearlitic structure.

Research performed by means of transmission electron microscopy proved that long-term service at elevated temperatures contributed to:

- processes of ferrite recovery and recrystallization revealed by decrease of dislocation density and formation of polygonized ferrite; Apart from recrystallized grains of ferrite, also strongly polygonized grains with high dislocation density could be observed (Fig. 1a);
- privileged precipitation of carbides on ferrite grain boundaries. Occasionally the number of precipitated carbides was so large that they formed the so-called “continuous grid of precipitates” (Fig. 1b);
- process of pearlite colonies degradation consisting in fragmentation, spheroidization and coagulation of pearlitic carbides (Fig. 1c).

Performed research has shown that processes of recovery and recrystallization occur faster in border areas of ferrite grains, where compound precipitates could be noticed (Fig. 1d). Identification revealed that precipitates of such kind were formed by carbides of MC and M_2C grade, where MC carbide is a “horizontal” precipitate while M_2C carbides are “vertical” precipitates. In literature these compound precipitates are called „H - carbide” [13].

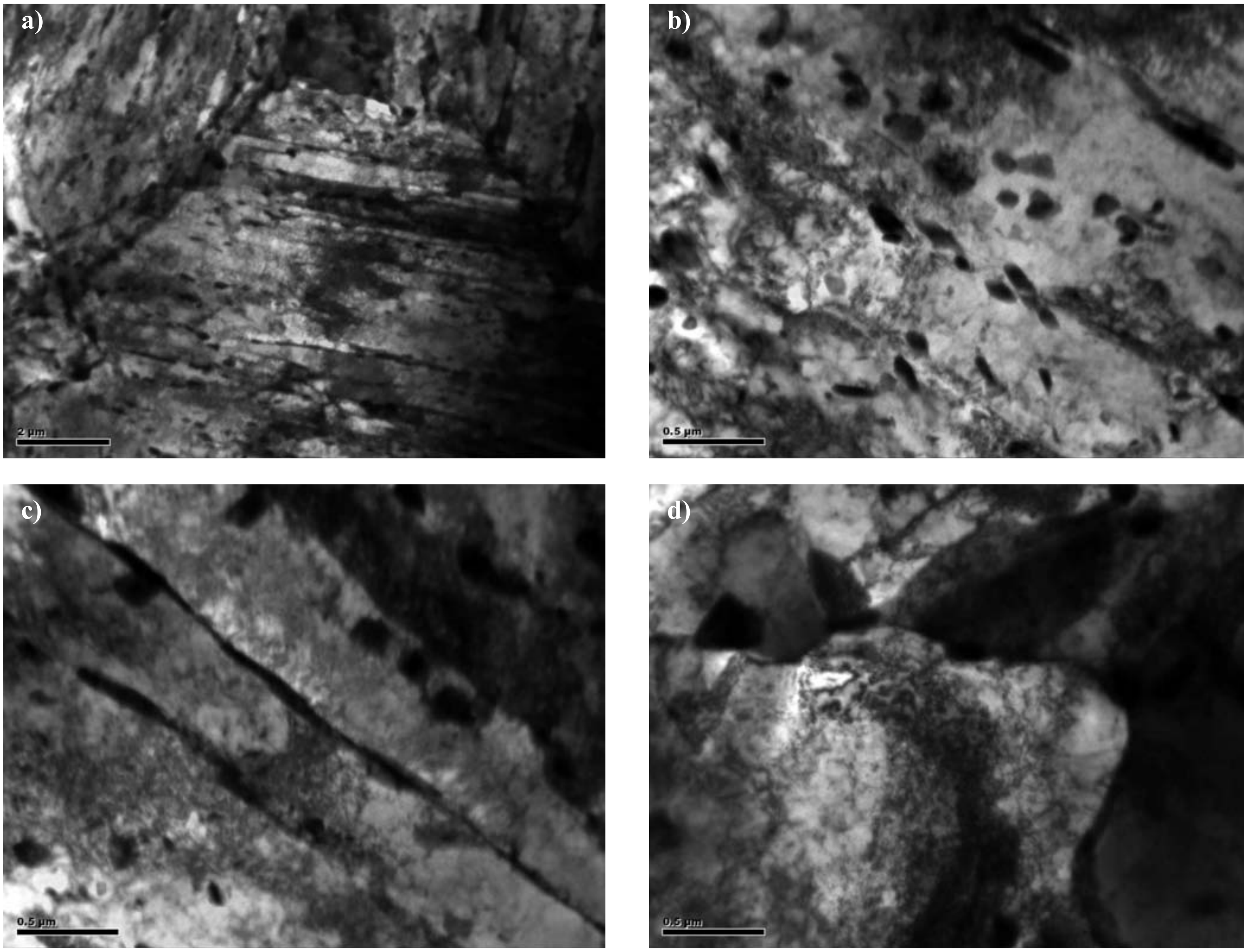

Fig. 2. Microstructure of the cast steel after regenerative heat treatment, TEM, thin foil

The analysis of chemical composition of carbides included in precipitates of „H – carbide" grade has shown that carbides of MC grade are molybdenum enriched, which indicates that there are changes occurring in the chemical composition of those carbides during operation.

According to [14], molybdenum content in MC carbides may amount even to 80%. Molybdenum enrichment of MC carbides enables needle-shaped precipitates of M_2C grade (molybdenum rich) to germinate on interfacial boundary of MC carbide/ferrite.

Formation of „H – carbide" complexes takes place at the expense of finely dispersive MC precipitates, which according to [14, 15], may lead to decrease of creep resistance.

Identification of precipitates carried out by means of selective micro diffraction revealed in the structure of the cast steel after long-term operation: M_7C_3 and $M_{23}C_6$ carbides on grain boundaries, MC and M_2C carbides as well as compound complexes of „H – carbide" type inside the grains, while in the areas of degraded pearlite: M_3C and M_7C_3 carbides.

3.2. After regenerative heat treatment

Applying of regenerative heat treatment (bainitic hardening combined with high-temperature tempering) caused obtaining of bainitic structure – Fig. 2a. Precipitates layout observed in the structure was characteristic of lower bainite –Fig. 2b. In the structure apart from precipitates of solid shape, as in Fig. 2b, there were also precipitates of elongated shape visible, which were located on packets boundaries – Fig. 2c. Identification proved presence of M_7C_3 and $M_{23}C_6$ carbides on packets boundaries, as well as MC and M_3C grade carbides inside bainite packets. A sample of calculated diffractogram is presented in Fig. 3. Average width of bainite packet was about 0.5μm. Matrix of the investigated cast steel after regenerative heat treatment was characterized by high dislocation density, however, few polygonized areas with lower dislocation density were also observed (Fig. 2d). Presence of polygonized areas in the cast steel after heat treatment may be caused by the difference in chemical composition of particular grains, resulting from dendritic micro segregation. Differences of chemical composition bring about local decrease of recrystallization temperature.

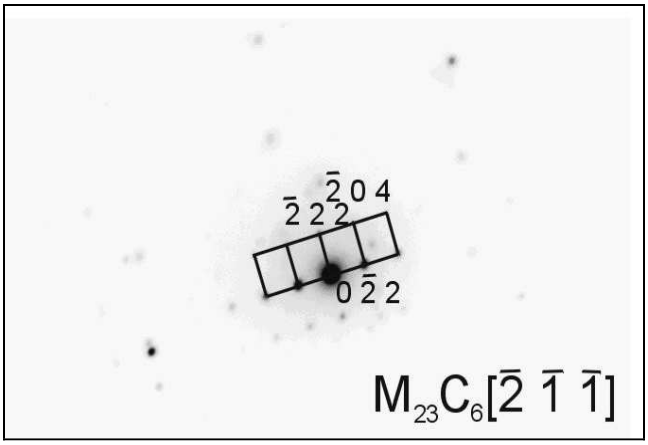

Fig. 3. Calculated diffractogram of M_{23} C_6 carbide

4. Conclusions

Microstructural research has shown that long-term service in creep conditions contributes to degradation of the structure through: processes of recovery and recrystallization of ferrite, privileged precipitation of carbides on grain boundaries, disintegration of pearlitic areas and formation of compound „ H – carbide" precipitates which indicate a significant degree of investigated material wear and tear.

Regenerative heat treatment, carried out at assumed temperature and time parameters, resulted in obtaining of high-tempered lower bainite structure in the investigated cast steel, which ensures obtaining of optimum combination of high mechanical properties and high impact energy.

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