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# Examination of Minor Phases in Martensitic 12% Cr-Mo-W-V Steel

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Martensitic 12% Cr-Mo-W-V Russian steel grade EP428 (0.17-0.23 C+N; <0.4 Si; 0.5-0.9 Mn; 10.5-12.5 Cr; 0.5-0.8 Ni; 0.5-0.7 Mo; 0.7-1.1 W; 0.15-0.3 V) is widely applied in electric power engineering as material for blades, rotors and disks of gas turbines [1] operating at 500-550$^0$C. But now, many turbine disks have exhausted their designed service life (140,000 h.) and examination of phase state and changes during long-term service exposure for this steel is a very urgent problem.

Studies have been carried out on specimens cut from GTK-10 HP disks made from EP428 steel after a standard heat treatment and various service times up to 138,519 h. The methods used in investigations were light optical metallography and analytical electron microscopy using EDX and EELS detectors as well as the electron microprobe analyzer. Carbon extraction replicas with the extracted strengthening phases in the disk metal have been examined.

Numerous measurement data on the hardness of disk material after service times of 40,000 h and above revealed strengthening of disk material; different disk regions at different service temperatures being equally strengthened [2]. The EP428 HP turbine disk metal microstructure after the factory heat treatment (consisting of austenitizing at 1050 $^0$C for 1 hour and oil cooling and tempering at 700 $^0$C for 10 h) is tempered martensite (Fig. 1) [3]. Electron microscopical images of the precipitates obtained by the carbon extraction replica method revealed that the major carbide phase is $M_{23}C_6$ (FCC lattice) with a size of 50-200 nm, where M is Cr, Fe, Mo, W and V, and is present on prior-austenite grain boundaries and martensite lath boundaries. Apart from this phase, the microstructure includes nanosized finely dispersed particles of $M_2X$ or $M_2(C,N)$ type carbonitrides, where M is Cr and V, based on a $Cr_2N$ phase having a needle-like morphology, and a small quantity of MX or M(C,N) type carbonitrides with a VC-based FCC crystal lattice including Cr and N in small amounts. The $M_2X$ phase with needle-like morphology has different sizes but a hexagonal crystal lattice of the same type (Fig. 2a, b). EDX spectrum showing the elements presence are given in Fig. 2c.

Determination of the chemical composition of the main carbide phase $M_{23}C_6$ using the EDX spectra established the Cr/Fe ratio as a function of temperature and exposure time. The Cr/Fe ratio increased linearly with increasing temperature and time of service exposure. The chemical composition of the minor phases, $M_2X$ and MX types, namely the amount of Cr, V and the light element N, was determined by EDX and EELS spectrometry. On the basis of these findings, the phase-structural reaction for strengthening phases in EP428 steel between 300-500 $^0$C is:

$$M_2X(1) \rightarrow \left\{ \begin{array}{l} MX' \\ M_2X(2) \rightarrow M_2X(3) + M_{23}C_6' \end{array} \right\} \rightarrow M_2X(3) + MX' + M_{23}C_6',$$

where phases $M_2X$(1, 2, 3) differ by chemical composition and morphology and $M_{23}C_6$' and MX' are secondary phases. A phase diagram for the service temperature range has been built based on phase presence data. The processes occurring in finely dispersed phases during long-term service provide an explanation for service strengthening of EP428 steel.

## References

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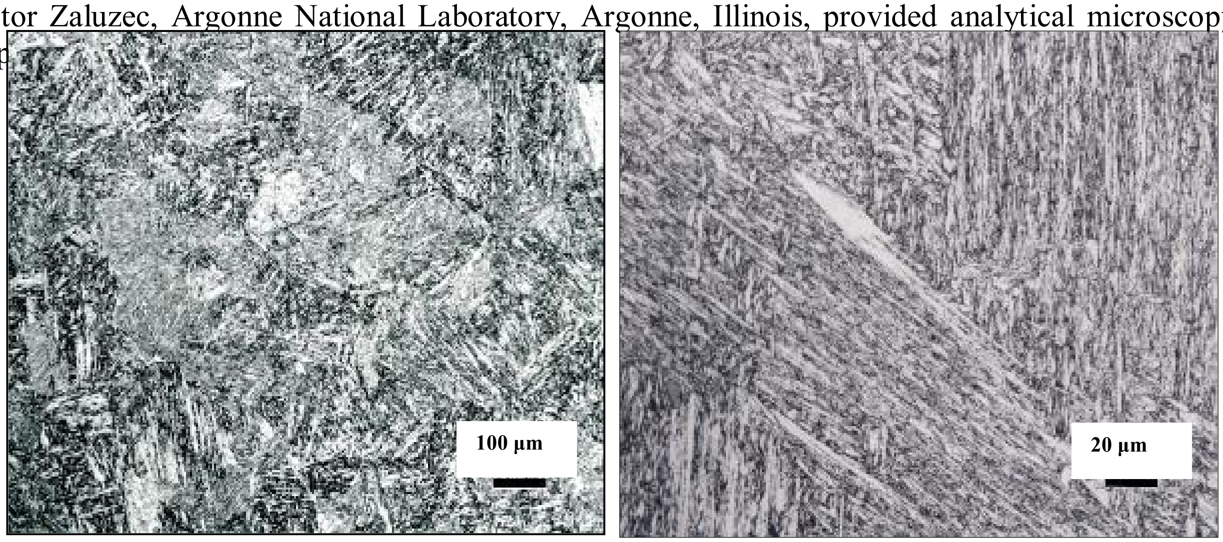


Fig. 1. Microstructure of disk metal produced from EP428 grade steel (Vilella's reagent).

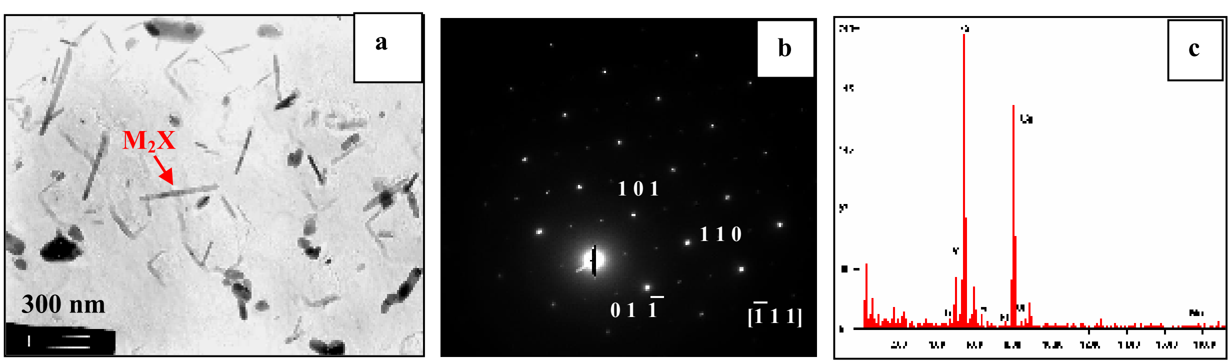


Fig. 2. $M_2X$ phase and its identification: a) extraction replica image of $M_2X$ phase; b) diffraction pattern from $M_2X$ phase; c) EDX spectrum, Cu peak is from a grid.

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