JPEDAV (2007) 28:286–288
DOI: 10.1007/s11669-007-9072-3
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C-Cr-Fe-Mo-V (Carbon-Chromium-Iron-Molybdenum-Vanadium)

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Cr-Mo-V steels are technologically important for creep-resistant applications. [2001Kro] assessed the phase equilibria of this quinary system and computed five isothermal sections for Fe-rich alloys and compared them with the available experimental results.

Binary Systems

For brief descriptions of the C-Cr, C-Fe, C-Mo, Cr-Fe, Cr-Mo, and Fe-Mo binary systems, see the C-Cr-Fe-Mo update in this issue. For descriptions of the C-V, Cr-V, and Fe-V binaries, see the C-Cr-Fe-V update in this issue. In the Mo-V system, a continuous body-centered cubic solid solution exists between Mo and V.

Ternary Systems

The C-Cr-Fe, C-Cr-Mo, C-Fe-Mo, and Cr-Fe-Mo ternary systems are briefly described in the C-Cr-Fe-Mo update in this issue. For the Fe-Mo-V system, [1992Rag] presented a schematic liquidus projection and two isothermal sections at 1297 and 897 °C. See [1995Vil] for data on the other ternary systems.

Quaternary Systems

Updates on the C-Cr-Fe-Mo and C-Cr-Fe-V systems appear in this issue. There appear to be no data on the C-Cr-Mo-V, C-Fe-Mo-V, and Cr-Fe-Mo-V systems.

Quinary Phase Equilibria

[1972And] prepared more than 150 compositions of three groups of steels, containing Cr-Mo, Cr-V, and Cr-Mo-V, respectively. All steels contained a constant (nominal) amount of 0.12 wt.% C and residual elements of 0.5 wt.% Mn and 0.5 wt.% Si. The samples were annealed at 650 and 700 °C up to 1000 h. Phase identification was done by x-ray diffraction of residues obtained by electrolytic extraction. The alloy carbides identified include Fe_3C, Cr_7C_3-based M_7C_3, $Cr_{23}C_6$-based $M_{23}C_6$, V_4C_3-based M_4C_3 (this is denoted as VC-based MC in this review), Fe_2MoC (ξ), $(Fe,Mo)_6C$-based M_6C, and Mo_2C-based M_2C. The approximate composition of the metallic elements in the extracted carbides was obtained by x-ray fluorescence analysis. The ratios of the partitioning of the alloying elements between matrix and carbide were estimated and listed. For the Cr-Mo-V steels, four isothermal sections were constructed as a function of Cr and Mo at 700 and 650 °C and at 0.5 and 1.0 wt.% V. Additional isothermal sections were constructed as a function of Cr and V at 700 °C and at constant Mo contents of 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, and 2 wt.% Mo, respectively.

[1998Vyr] vacuum-melted four Cr-Mo-V steels containing in weight percent: 0.09-0.12 C, 2.40-2.62 Cr, 0.70-0.95 Mo, and 0.02-0.34 V. Residual Mn and Si contents were about 0.7 and 0.3 wt.%, respectively. The steels were quenched from 1250 °C to produce a martensitic structure and then annealed (tempered) between 500 and 720 °C up to 1000 h. Extracted carbide particles were analyzed by electron diffraction and energy dispersive x-ray spectroscopy. The alloy carbides found were M_3C, $M_{23}C_6$, M_2C, M_7C_3, MC, and M_6C. The carbides identified after each annealing treatment were listed along with those predicted from equilibrium calculations for all the four steels. Time-temperature diagrams were constructed to illustrate the carbide precipitation kinetics.

In an accompanying paper, [1998Kro] carried out a more detailed thermodynamic analysis of the carbide type and its stability as a function of temperature using the CALPHAD approach. The qualitative conclusions are as follows. With increasing temperature, in steels containing more than 0.1 wt.% V, the equilibrium phases were: $\alpha + M_{23}C_6 + MC + M_6C$, $\alpha + M_{23}C_6 + M_7C_3 + MC + M_6C$, $\alpha + M_7C_3 + MC + M_6C$, and $\alpha + M_7C_3 + MC$. The same equilibria were observed without MC in steels containing 0.02 wt.% V. M_6C is stable for all investigated compositions at lower temperatures. It dissolves above 620-680 °C. Its stability comes mainly from Mo. Full agreement between the computed carbide distribution and the experimental results is found at higher temperatures only, indicating that the carbide distribution is far from equilibrium at lower temperatures. The Mo/V ratio and the absolute Mo and V contents determine primarily the carbide evolution during tempering.

[2000For] studied samples of three industrial low-alloy steels exposed to long periods (30,900-141,500 h) in power plants at the temperature interval of 500-510 °C. Extracted carbide particles were analyzed by electron diffraction and energy dispersive x-ray spectroscopy. The alloy carbides found were $M_{23}C_6$, M_2C (cph), M_7C_3, MC, and V_4C_3. The measured compositions of the carbides were listed. The experimental compositions did not agree with the calculated

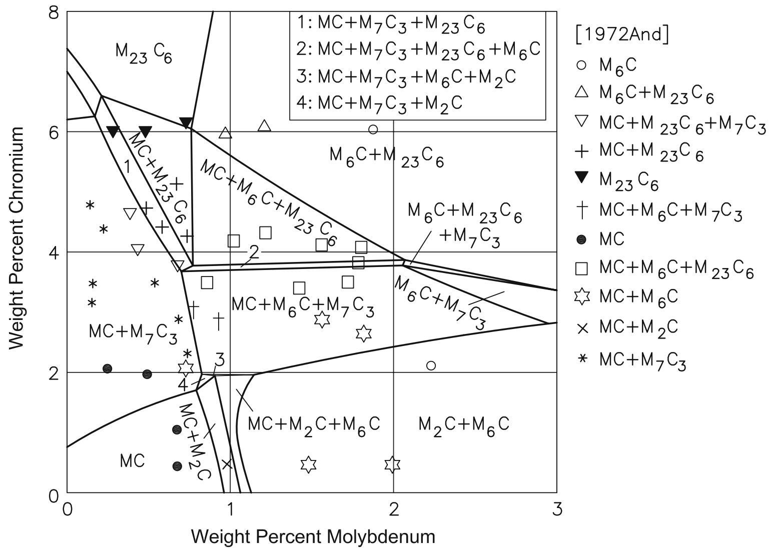

Fig. 1 C-Cr-Fe-Mo-V computed isothermal section at 700 °C, 0.12 wt.% C and 0.5 wt.% V [2001Kro]

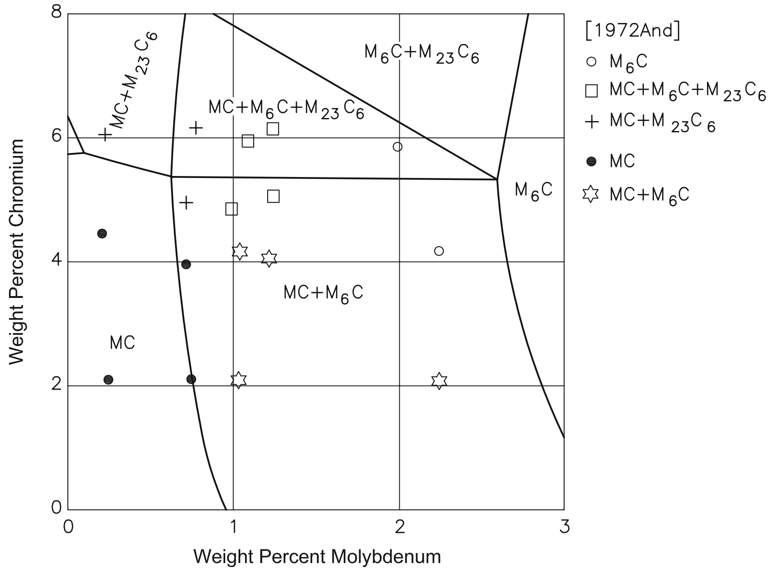

Fig. 2 C-Cr-Fe-Mo-V computed isothermal section at 700 °C, 0.12 wt.% C and 1.0 wt.% V [2001Kro]

values. [2000For] attributed the disagreement either to the lack of equilibrium at this low temperature even after prolonged exposure or to the extrapolation of the thermodynamic parameters from high temperatures.

[2001Kro] developed a thermodynamic description of this quinary system and computed seven isothermal sections and compared them with the experimental data of [1972And], [1998Vyr], and [2000For]. The interaction parameters were taken from the assessments of [1992Qiu] for C-Cr-Fe-Mo and from [1992Lee] for C-Cr-Fe-V. The parameters that were newly assessed, modified, and listed by [2001Kro] are those related to the face-centered cubic solid solution (γ), M_2C (cph), M_6C, and $M_{23}C_6$. Four computed isothermal sections at 650 and 700 °C and at the compositions (in wt.%) of 0.12C-0.5V and 0.12C-1.0V at each temperature were compared with the results of [1972And]. Figures 1 and 2 show the isothermal sections at 700 °C and at 0.5 and 1 wt.% V, respectively. The agreement with the experimental results is fair. At 650 °C, the phase distribution is the same as at 700 °C. Figure 3 shows the computed isothermal section at 500 °C and at 0.11 wt.% C-0.32 wt.% V, compared with three experimental points of [1998Vyr] and [2000For]. The agreement is satisfactory only for Cr content of less than 1 wt.%. Figure 4 shows the computed section at 700 °C for the same steel. There is agreement with the two experimental points from [1998Vyr]. Figure 5 is an isothermal section at 510 °C and at 0.16 wt.% C-0.29 wt.% V. A partial

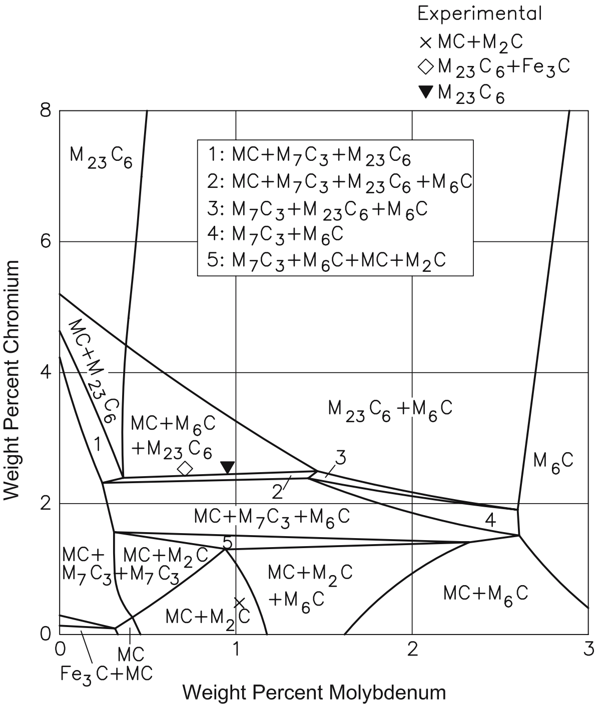

Fig. 3 C-Cr-Fe-Mo-V computed isothermal section at 500 °C, 0.11 wt.% C and 0.32 wt.% V [2001Kro]

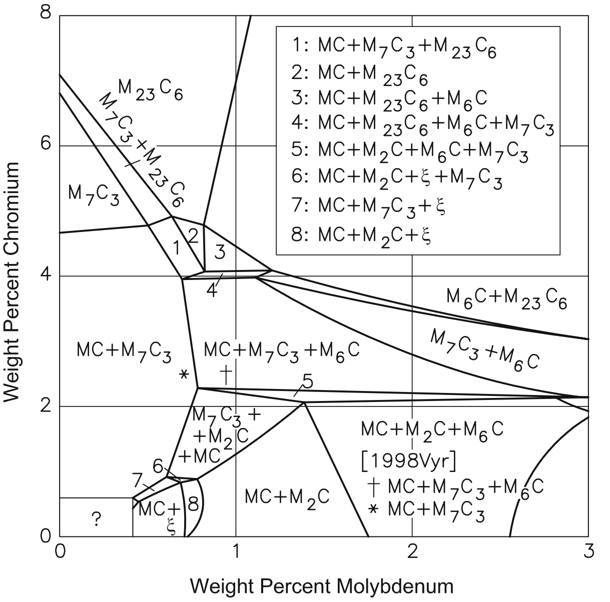

Fig. 4 C-Cr-Fe-Mo-V computed isothermal section at 700 °C, 0.11 wt.% C and 0.32 wt.% V [2001Kro]

agreement is seen with the experimental points. In Figs. 3-5, the experimental data are rather meager. In Figs. 4 and 5, the phase boundaries falling within the box at the bottom left are omitted, as they are crowded and unclear in the figures of [2001Kro].

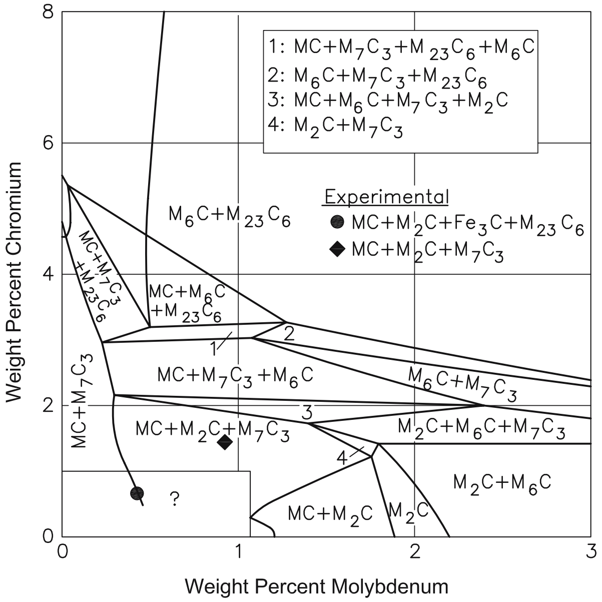

Fig. 5 C-Cr-Fe-Mo-V computed isothermal section at 510 °C, 0.16 wt.% C and 0.29 wt.% V [2001Kro]

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