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Al-Fe-Pd (Aluminum-Iron-Palladium)

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The previous review of this system by [1992Rag] presented a pseudobinary section along the Fe-AlPd join and an isothermal section at 500 °C, with the latter based on the work of [1988Fil]. No ternary compounds were reported in the Al-rich region at 500 °C. Recently, [2004Bal] investigated the phase relationships in the temperature range of 1020 to 900 °C and found the occurrence of several ternary phases in Al-rich alloys.

Binary Systems

The Al-Fe phase diagram [1993Kat] shows that the face-centered cubic (fcc) solid solution based on Fe is restricted by a γ loop. The body-centered cubic (bcc) solid solution α exists in the disordered *A*2 form, as well as the ordered *B*2 and $D0_3$ forms. Apart from the high-temperature phase ε, there are three other intermediate phases in the system: $FeAl_2$ (triclinic), Fe_2Al_5 (orthorhombic), and $FeAl_3$ or Fe_4Al_{13} (monoclinic). In the Al-Pd system [1986McA], a number of intermediate phases occur: Al_4Pd (hexagonal), Al_5Pd_2 (orthorhombic); Al_3Pd_2 (Al_3Ni_2-type hexagonal), three modifications of AlPd (two cubic and one rhombohedral), Al_3Pd_5 (Ge_3Rh_5-type orthorhombic), $AlPd_2$ (Co_2Si-type orthorhombic), and Al_2Pd_5 (Ga_2Pd_5-type orthorhombic). Recently, [2001Yur] reported two more high-temperature orthorhombic phases, ε_6 and ε_{28}, close to the Al_3Pd composition. The Fe-Pd phase diagram [1982Kub] is characterized by the presence of a continuous solid solution γ in the temperature range of 1300 to 900 °C between the Fe-based fcc phase and Pd. Two superstructures FePd (AuCu type tetragonal) and $FePd_3$ ($AuCu_3$ type cubic) form congruently from γ at 790 and 820 °C, respectively, and have appreciable homogeneity ranges at lower temperatures.

Ternary Phases

[2004Bal] studied the phase equilibria in Al-rich alloys in the temperature range of 1020 to 900 °C and found three ternary cubic phases designated *C* (space group $Pm\bar{3}$, a = 0.7655 nm), C_1 ($Im\bar{3}$, a = 1.5389 nm), and C_2 ($Fm\bar{3}$, a = 1.5510 nm), each with a significant homogeneity range. An orthorhombic phase *O* (space group *Cmca*, a = 1.5499, b = 0.8102, and c = 2.3848 nm) occurs close to the monoclinic binary phase $FeAl_3$. In the ternary region adjacent to the binary high-temperature orthorhombic phases ε_6 and ε_{28} of the Al-Pd system, two additional structure variants, ε_{16} and ε_{22}, were found. [2004Bal] clubbed all the ε variants together and designated the ternary region as ε in the isothermal section at 900 °C.

Ternary Isothermal Sections

Using starting metals of purity 99.999% Al, 99.99% Fe, and 99.95% Pd, [2004Bal] induction-melted alloy compositions under an argon atmosphere. The samples were annealed at 1020, 995, 975, and 900 °C for 24 to 2043 h. The phase equilibria were studied with scanning and transmission electron microscopy, and the x-ray diffraction technique. The compositions of the phases were determined by the inductively coupled plasma optical emission spectroscopy and by energy-dispersive x-ray analysis. The melting

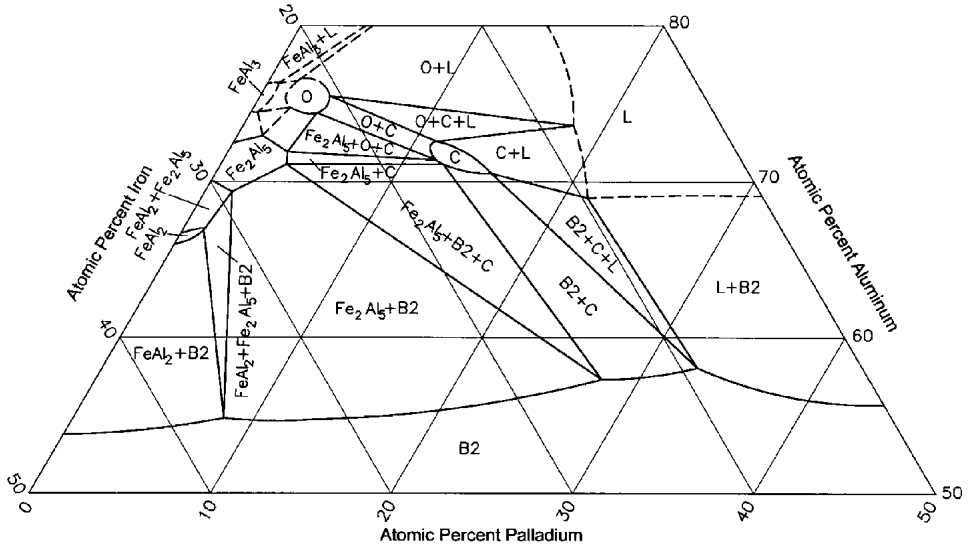

Fig. 1 Al-Fe-Pd isothermal section at 1020 °C [2004Bal]

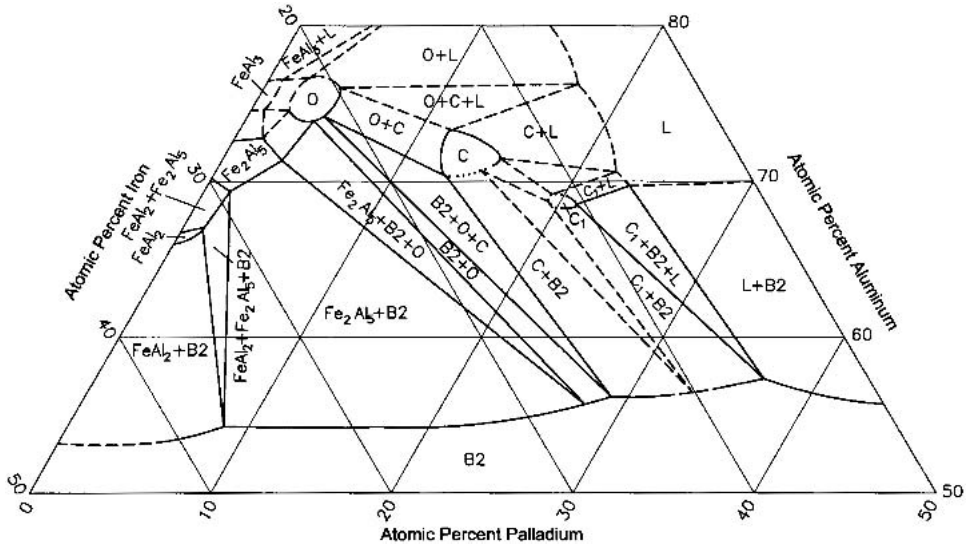

Fig. 2 Al-Fe-Pd isothermal section at 995 °C [2004Bal]

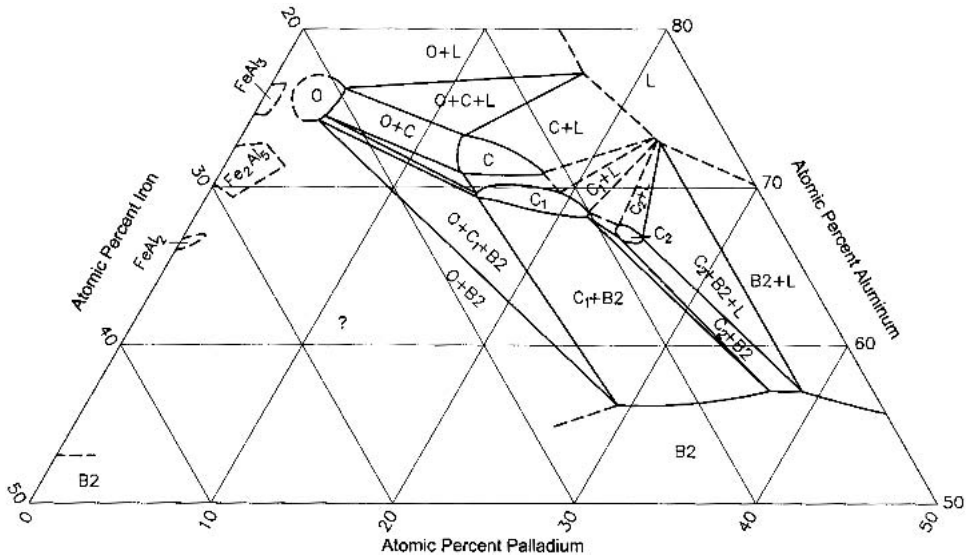

Fig. 3 Al-Fe-Pd isothermal section at 975 °C [2004Bal]

temperatures of the phases were determined by differential thermal analysis. The isothermal sections constructed by [2004Bal] at 1020, 995, 975, and 900 °C are redrawn in Fig. 1 to 4 to agree with the accepted binary data.

At 1020 °C (Fig. 1), the ternary phases *C* and *O* are stable. The *O* phase is centered around the composition (at.%) $Al_{75.4}Fe_{21.8}Pd_{2.8}$ and dissolves up to 4.2 at.% Pd. The *C* phase has a composition range of $Al_{72.4}Fe_{16.4}Pd_{11.2}$ to $Al_{70.4}Fe_{14.1}Pd_{15.5}$. The CsCl-type *B*2 phase dissolves up to 57.8 at.% Al at 33.4 at.% Pd. $FeAl_2$, Fe_2Al_5, and $FeAl_3$ dissolve up to 1.4, 3.9, and 1.0 at.% Pd, respectively. At 995 °C (Fig. 2), the ternary phases *C*, C_1, and *O* are present. The *O* phase contains ~74 to 76.5 at.% Al and up to ~4.4 at.% Pd. The *C* phase is centered around the composition $Al_{71.6}Fe_{14.8}Pd_{13.6}$. The homogeneity range of C_1 is small, around $Al_{68.5}Fe_{11.0}Pd_{20.5}$. The solubility in the *B*2 phase is up to 57.4 at.% Al at 37.0 at.% Pd. $FeAl_2$, Fe_2Al_5, and $FeAl_3$ dissolve about 1.2, 3.4, and 1 at.% Pd, respectively.

At 975 °C (Fig. 3), four ternary phases, *C,* C_1, C_2, and *O*, are stable. The composition range of *C* is wider than at 995 °C and extends to higher Pd contents. The homogeneity region of C_1 is also wider, compared to that at 995 °C and ranges from $Al_{69.5}Fe_{15.7}Pd_{14.8}$ to $Al_{68.2}Fe_{10.2}Pd_{21.6}$. The C_2 phase occupies a narrow region around $Al_{67.0}Fe_{8.5}Pd_{24.5}$. At 900 °C (Fig. 4), in addition to the above four ternary phases, the ε structural variants, which form below 940 °C, are present, and the region is marked as a single phase ε in Fig. 4, with a range of $Al_{75.5}Fe_{10}Pd_{14.5}$ to $Al_{72.1}Fe_{4.8}Pd_{23.1}$ [2004Bal]. The ε_{16} variant occurs at higher Fe concentrations, and the ε_{22} variant occurs at lower Fe concentrations.

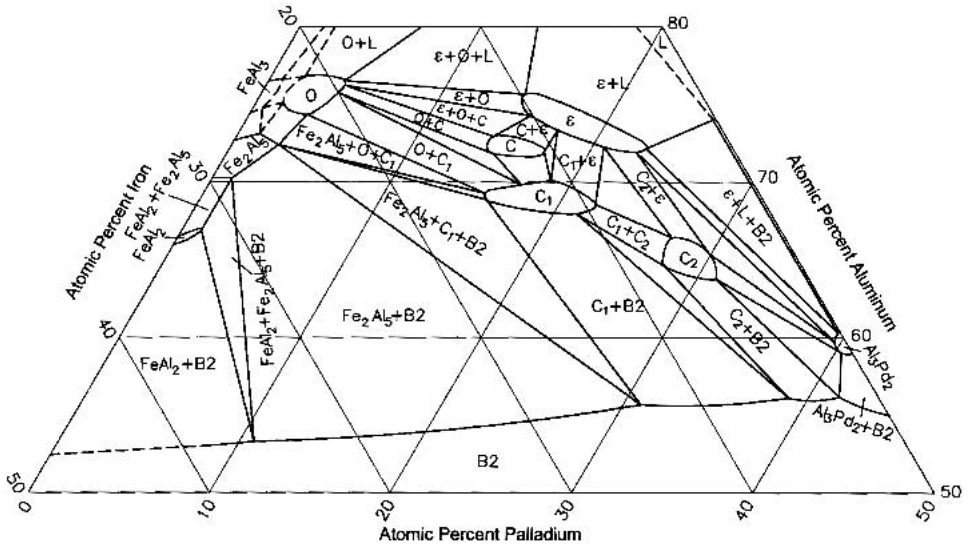

Fig. 4 Al-Fe-Pd isothermal section at 900 °C [2004Bal]

The *B*2 phase dissolves 56.2 at.% Al at 41.8 at.% Pd. The Pd solubility in $FeAl_2$ is 1 at.%, and the Fe solubility in Al_3Pd_2 is 1.1 at.%. The *C*, C_1, and C_2 phases shift to higher Pd levels, compared to those at higher temperatures. [2004Bal] pointed to the possibility of the occurrence of a stable or a metastable decagonal (quasicrystalline) phase around the composition $Al_{75.5}Fe_{12.5}Pd_{12}$ and concluded that further studies are required to clarify this point.

In contrast to the results of [1988Fil] that were reviewed in [1992Rag], [1992Rae] found that, at 500 °C, AlPd and FeAl form a continuous solid solution, and Al_4Pd and Al_3Pd_2 dissolve 10 and 23 at.% Fe, respectively.

Note Added in Proof:

In continuation of their study of the Al-rich alloys of this ternary system, Balanetskyy et al. [S. Balanetskyy, B. Grushko, T.Ya. Velikanova, and K. Urban, An Investigation of the Al-Pd-Fe Phase Diagram Between 50 and 100 at.% Al: Phase Equilibrium at 750 °C, *J. Alloy. Compd.,* Vol 376, 2004, p 158-164] determined an isothermal section at 750 °C using the same experimental procedures and techniques as above. They found an additional orthorhombic phase denoted N at the composition $Al_{76.5}Fe_{13.0}Pd_{10.5}$ with approximate lattice parameters of $a = 2.31$ nm, $b = 1.60$ nm and $c = 4.70$ nm. This phase is structurally related to the ε-phases and decagonal quasicrystals. It is in three-phase equilibrium with O and ε phases at 750 °C. The C phase was not found at this temperature.

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