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The Co-Cr-Ta (Cobalt-Chromium-Tantalum) System

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Introduction

Very little work has been done in the Co-Cr-Ta system. Only the face-centered-cubic (fcc) γCo phase boundary has been established at high temperature. The aging of Co-Cr-Ta alloys has been studied and is reported here.

Binary Systems

Two evaluated versions of the Co-Cr phase diagram are shown in Fig. 1(a) [1978All, 1990Gup] and (b) [Massalski2]. The two versions are in quite close accord except for the Co-rich region below ~900 °C. The two agree with regard to the following. Above 1300 °C, the Co-Cr system is a simple eutectic system with the eutectic reaction, L $\leftrightarrow$ (Cr) + (γCo), occurring at 1395-1397 °C. At 1283 °C, the (Cr) solid solution undergoes a congruent transformation to a σ phase. A eutectoid reaction, (Cr) $\leftrightarrow$ σ + (γCo), occurs near 1260-1266 °C. A peritectoid reaction, (γCo) + σ $\leftrightarrow$ (εCr), occurs at 967 °C. Lack of agreement between the two evaluated diagrams occurs (a) in the composition region with compositions of <~35 at.% Cr at temperatures below ~900 °C, where extensive studies have not been made, and (b) in a region like those found in all Co-rich alloys, where the establishment of equilibrium conditions is difficult because the (εCo) $\leftrightarrow$ (γCo) transformation is sluggish and is complicated by extensive faulting. In Fig. 1(b), the interpretation of the ferromagnetic to paramagnetic transformation, (γ_fCo) $\leftrightarrow$ (γ_pCo), is likely to be valid because similar behavior is observed in other systems, e.g., Co-V, Co-Mn [1981Ind1, 1981Ind2, 1982Ind, 1982Mio]. This interpretation treats the transformation as being second-order, occuring with a decrease in temperature and with an increase in Cr content. The decrease continues to ~855 °C, and at that temperature the transformation changes to first order. Insert in Fig. 1(a) shows the existence of three phases. Co_3Cr, Co_2Cr, and Co_3Cr_2, suggested by [1961Gri] as forming congruently at ~620, ~640, and, ~625 °C. Of these phases, the existance of the Co_3Cr phase has been confirmed by [1969Sin], but no confirmation has been found to corroborate the existance of the other two phases Co_2Cr and Co_3Cr_2. The uncertainties with regard to this low-temperature, Co-rich region are not relevant to the present discussion of the ternary system, since the ternary data pertain to higher temperatures.

The Co-Ta system [Massalski2] (Fig. 2) and [1996Gar] shows the existence of six intermediate phases: Co_7Ta_2; three Laves phases λ_1, λ_2, and λ_3; Co_6Ta_7 (μ); and $CoTa_2$. The $CoTa_2$ and the λ_3 phases form through peritectic reactions L + (Ta) $\leftrightarrow$ $CoTa_2$ at 1800 °C, and L + λ_2 $\leftrightarrow$ λ_3 at 1450 °C. The λ_2 and μ phases melt congruently at 1620 and 1700 °C, respectively. The λ_1 and Co_7Ta_2 phases form through peritectoid reactions μ + λ_2 $\leftrightarrow$ λ_1 at 1540 °C and λ_3 + (γCo) $\leftrightarrow$ Co_7Ta_2 at 950 °C. Three eutectic reactions, L $\leftrightarrow$ μ + $CoTa_2$, L $\leftrightarrow$ μ + λ_2, and L $\leftrightarrow$ (γCo) + λ_3, occur at 1670, 1570, and 1280 °C, respectively. The λ_1 phase undergoes a eutectoid transformation λ_1 $\leftrightarrow$ μ + λ_2 at 1130 °C. The reaction through which fcc (γCo) changes to close-packed hexagonal (cph) (εCo) is not well established. [1967Ram] suggested a peritectoid reaction (γCo) + Co_7Ta_2 $\leftrightarrow$ (εCo) at ~1000 °C. However, the Co_7Ta_2 phase is stable only below 950 °C. If the peritectoid reaction of formation of (εCo) occurs, it must be below 950 °C.

The Cr-Ta system [Massalski2] (Fig. 3) shows only one intermediate phase, Cr_2Ta, in two polymorphic forms. The Cr_2Ta (HT) phase melts congruently at 2020 °C, and Cr_2Ta (LT) forms through a peritectoid reaction Cr_2Ta (HT) + (Ta) $\leftrightarrow$ Cr_2Ta (LT) at 1695 °C. The Cr_2Ta (HT) transforms through a eutectoid reaction Cr_2Ta (Ht) $\leftrightarrow$ (Cr) + Cr_2Ta (LT). Two eutectic reactions L $\leftrightarrow$ (Cr) + Cr_2Ta (HT) and L $\leftrightarrow$ Cr_2Ta (HT) + (Ta) occur at 1760 and 1965 °C, respectively.

Binary and Ternary Phases

In the three binary systems, Co-Cr, Co-Ta, and Cr-Ta, 11 intermediate phases form. Very little information is available for the ternary system, and no ternary phase has been reported. The structure data for binary phases are given in Table 1.

Ternary System

The Co-Cr-Ta system was studied at the Co end by [1965Dra]. The alloys were prepared by arc melting pure metals (99.9 mass% Co, 99.35 mass% Cr, and 99.9 mass% Ta) in the composition range up to 0-25 wt.% Cr and 0-35 wt.% Ta. The alloys were sealed in evacuated silica tubes annealed for 1000 h at 1200 °C, and then quenched in water. X-ray diffraction (XRD) and metallography were used for phase identification, and the fcc (γCo) phase boundary was determined. In the multiphase alloys, XRD of solid samples showed the presence of an $MgNi_2$ type λ_3 phase at 1200 °C. The solubility limit of the (γCo) phase region in the Co-Cr-Ta system is shown in Fig 4. The (γCo) phase boundary of Fig. 4 does not agree with the solubility limits given by the accepted Co-Cr and Co-Ta binary data. The solubility limit of (γCo) phase in the Co-Cr system is ~39 wt.% Cr at 1200 °C. Thus, at the Co-Cr binary, the (γCo) phase boundary of the Co-Cr-Ta system should be ~39 mass% Cr, as indicated by the dashed line in Fig. 4. On the Co-Ta side of the Co-Cr-Ta system (Fig. 4), the phase boundary is slightly above 10 mass% Ta, whereas the Co-Ta diagram shows it to

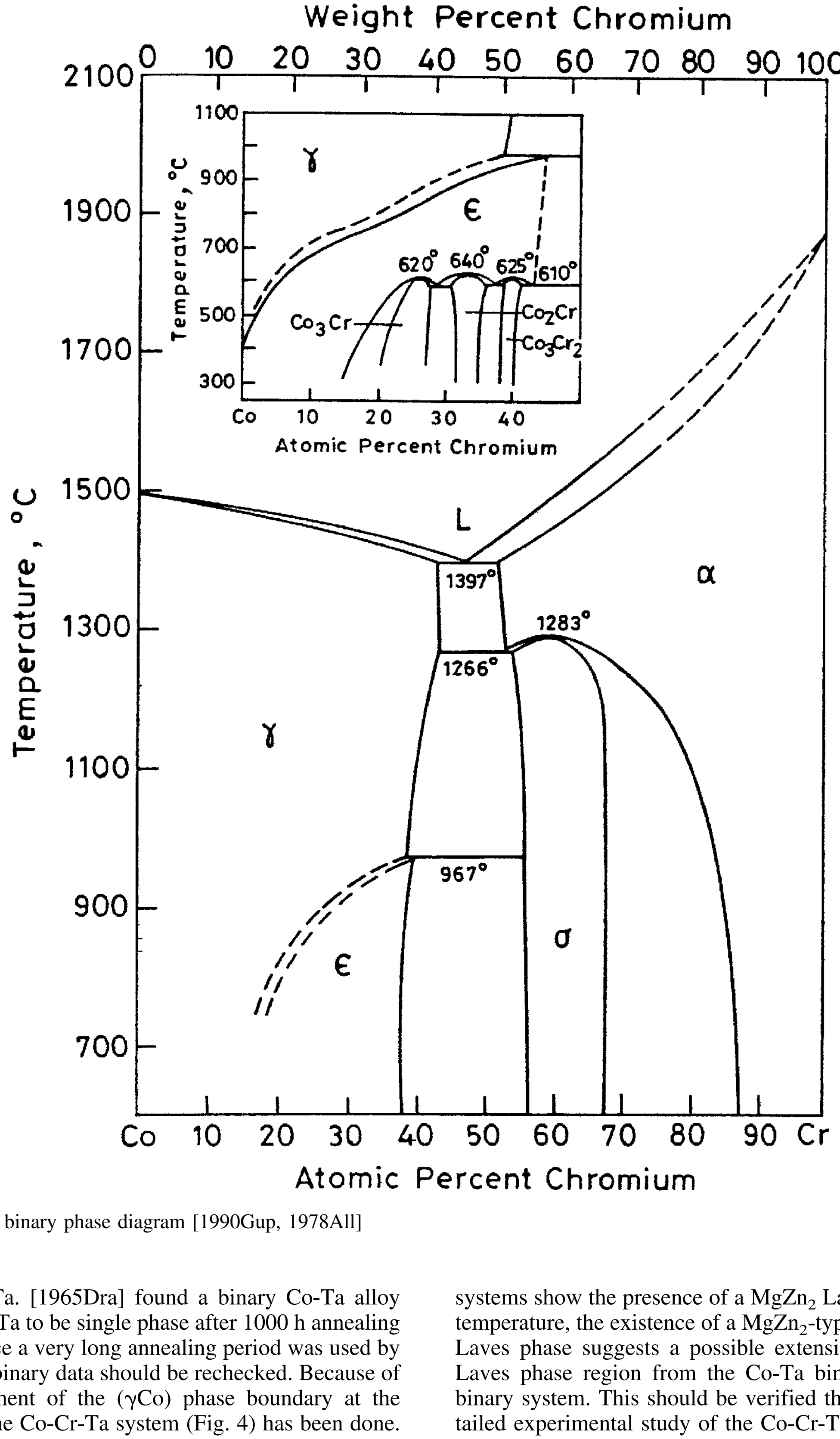

Fig. 1(a) Co-Cr binary phase diagram [1990Gup, 1978All]

be ~6 mass% Ta. [1965Dra] found a binary Co-Ta alloy with 10 mass% Ta to be single phase after 1000 h annealing at 1200 °C. Since a very long annealing period was used by [1965Dra], the binary data should be rechecked. Because of this, no adjustment of the (γCo) phase boundary at the Co-Ta side of the Co-Cr-Ta system (Fig. 4) has been done.

In the Co-Cr-Ta system, the presence of a ternary $MgZn_2$-type Laves phase at the CoCrTa composition was reported by [1967Lav]. Since both the Co-Ta and Cr-Ta systems show the presence of a $MgZn_2$ Laves phase at high temperature, the existence of a $MgZn_2$-type CoCrTa ternary Laves phase suggests a possible extension of the $MgZn_2$ Laves phase region from the Co-Ta binary to the Cr-Ta binary system. This should be verified through a more detailed experimental study of the Co-Cr-Ta system.

A part of the 1200 °C annealed specimens were aged at 1000, 800, 700, and 600 °C for 2-250 h. A hardness measurement of the aged alloys showed an increase in hardness

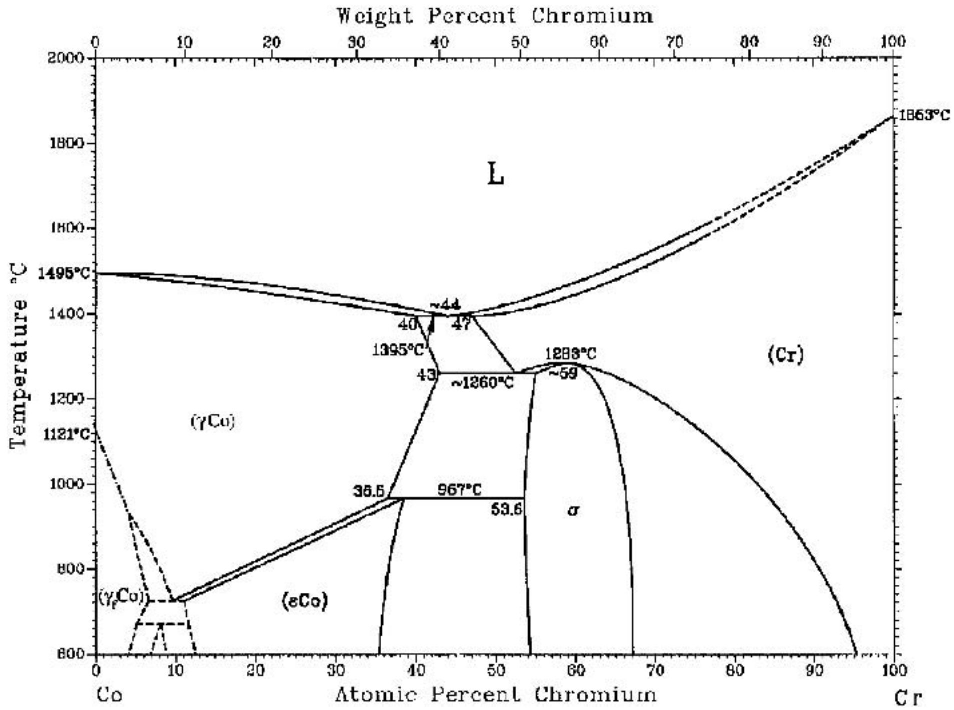

Fig. 1(b) Co-Cr binary phase diagram [Massalski2]

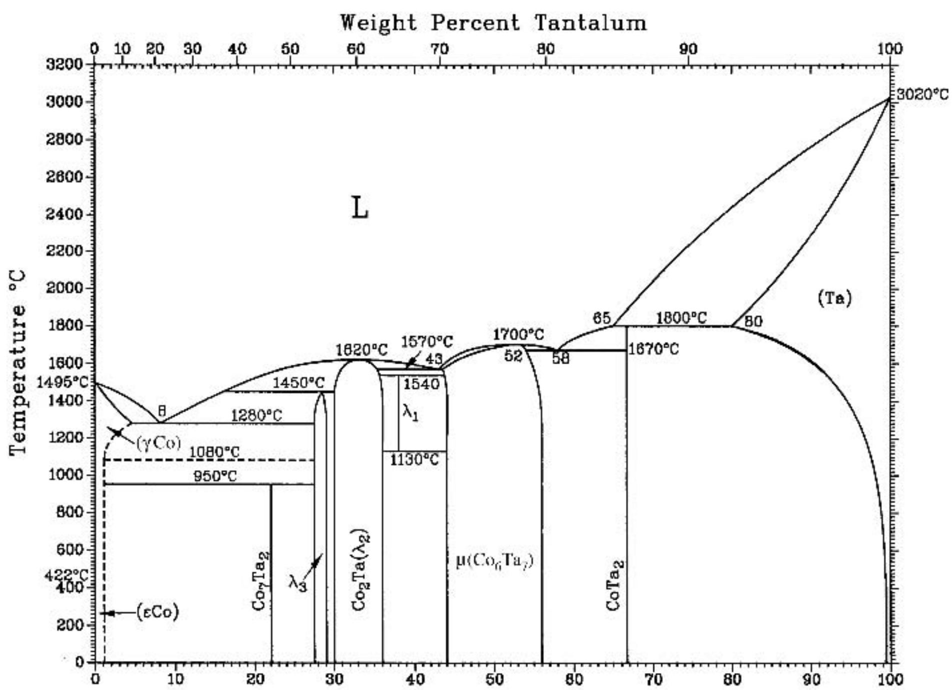

Fig. 2 Co-Ta binary phase diagram [Massalski2]

with an increase in Cr and Ta content, and the maximum change in hardness occurred at 700 °C. A more detailed investigation of the aging of Co-Cr-Ta alloys was carried out with two alloys containing 8 mass% Cr and 10 mass% Ta and 15 mass% Cr and 8 mass% Ta. Aging of the solution-treated (1200 °C for 2 h) alloys was carried out for 16 h and 100 h at various temperatures (i.e., 600, 700, 800, and 1000 °C). For both aging times, the maximum increase in hardness was produced at 700 °C. One hundred hours of aging at 700 °C produced an increase in hardness greater

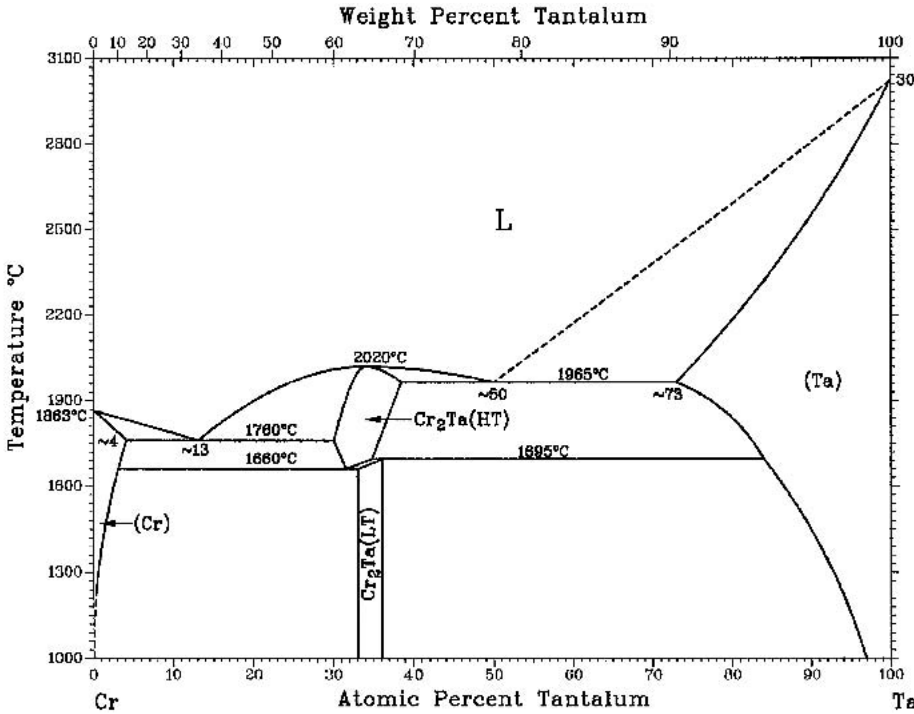

Fig. 3 Cr-Ta binary phase diagram [Massalski2]

Table 1 Phases present in binary systems Co-Cr, Co-Ta, and Cr-Ta and their structure data

Phase designation	Composition	Pearson's symbol	Space group	Type	Lattice parameter, nm a	Lattice parameter, nm c
α	(Cr), (Ta)	*cI*2	$Im\overline{3}m$	W	…	…
γ	(γCo)	*cF*4	$Fm\overline{3}m$	Cu	…	…
ε	(εCo)	*hP*2	$P6_3/mmc$	Mg	…	…
σ	Co_7Cr_8	*tP*30	$P4_2/mnm$	σ (Cr,Fe)	0.8758	0.4536
ζ	Co_3Cr_2	…	…	…	…	…
ν	Co_2Cr	…	…	…	…	…
π	Co_3Cr	*hP*8	$P6_3/mmc$	Ni_3Sn	0.5028	0.4034
ρ_1(a)	αCo_3Ta	*cP*4	$Pm\overline{3}m$	$AuCu_3$	0.3647	…
ρ_2(a)	βCo_3Ta	*hR*12	$R\overline{3}m$	$BaPb_3$	0.51864	1.8870
λ_3	$Co_{74}Ta_{26}$	*hP*24	$P6_3/mmc$	$MgNi_2$	0.476	1.550
λ_2	Co_2Ta	*cF*24	$Fd\overline{3}m$	Cu_2Mg	0.6783	…
	Cr_2Ta (LT)	*cF*24	$Fd\overline{3}m$	Cu_2Mg	0.6985	…
λ_1	$Co_{62}Ta_{38}$	*hP*12	$P6_3/mmc$	$MgZn_2$	0.4836	0.786
	Cr_2Ta (HT)	*hP*12	$P6_3/mmc$	$MgZn_2$	0.4932	0.8082
μ	Co_6Ta_7	*hR*13	$R\overline{3}m$	Fe_7W_6	0.4928	2.644(b)
τ	$CoTa_2$	*tI*12	$I4/mcm$	Al_2Cu	0.6115	0.4972

(a) Co_3Ta (ρ) phase has been reported to have two crystal modifications [1996Gar]. (b) Lattice parameters of hexagonal cell

than two times the hardness of the solution-treated alloy. At 800 °C, hardness decreased considerably due to overaging, and the extracted precipitate particles on XRD showed the precipitated phase to be βCo_3Ta. On aging at 700 °C for 16 h, electron micrographs showed a finely dispersed precipitated phase. Electron diffraction showed diffraction spots due to a cubic (γCo) matrix phase together with cubic superstructure diffraction spots oriented paralled to the {111} planes. The cubic superstructure phase was found to be related to the (γCo) cubic αCo_3Ta phase. Electron diffraction also showed the presence of regions with hexagonal structure in the solid solution phase. The phase regions with hexagonal structure also showed the presence of a superstructure that was not identified. It was concluded that the observation of the αCo_3Ta-related superstructure in cubic phase regions is due to the first stage of formation of the αCo_3Ta metastable phase reported by [1959Kor] in their study of the Co-Ta system.

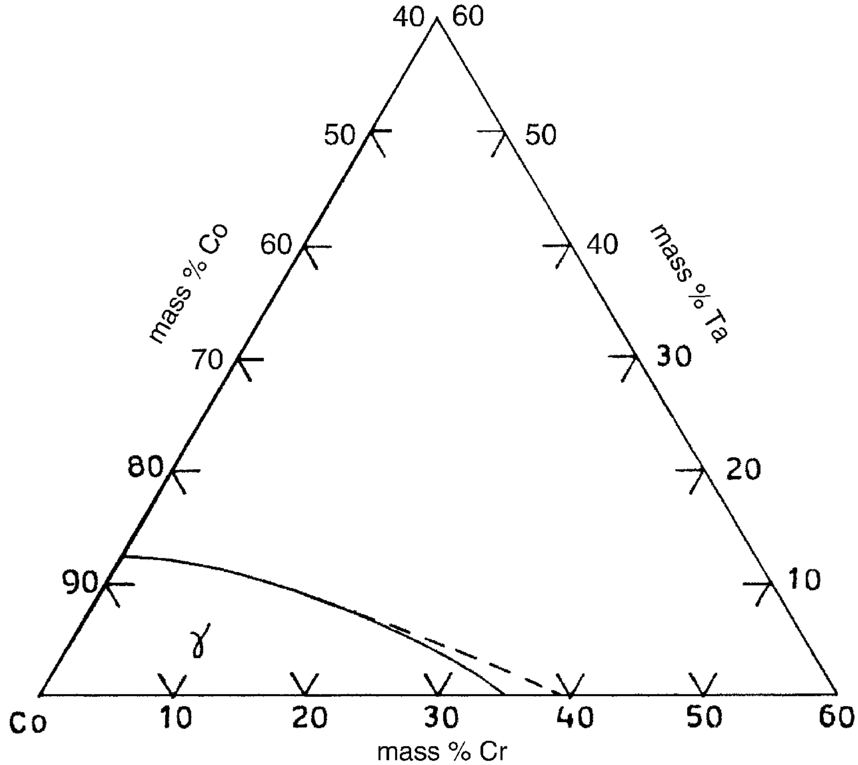

Fig. 4 A partial isothermal section of Co-Cr-Ta system at 1200 °C showing the fcc (γCo) phase boundary. Dashed line indicates the probable phase boundary on the Co-Cr side of the diagram.

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# Indicates presence of phase diagram.

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