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Journal of Alloys and Compounds 262–263 (1997) 258–262

Journal of ALLOYS AND COMPOUNDS

The Sc–Ni system

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Abstract

The Sc–Ni system was reinvestigated because of the need of more accurate data for the study of the phase equilibria of the Sc–Ti–Ni ternary system. Sc–Ni alloys melted from the components were characterized using X-ray, metallographic, differential thermal and electron microprobe analyses. In contrast to the former diagram of the Sc–Ni system, the Sc_2Ni phase is formed by the peritectical reaction $L + \delta \rightleftarrows \eta$ at 990°C. It was found that the transformation in the scandium-based alloys occurs via the metatectic reaction $\beta \rightleftarrows L + \alpha$ (where α is the hpc and β the bcc modification of scandium) at 950°C. The eutectic reaction, $L \rightleftarrows Sc_2Ni + \alpha_{Sc}$, takes place at 840°C. As a result of the study of the Sc–Ni system the binary phase diagram was constructed. © 1997 Elsevier Science S.A.

Keywords: Alloys; Nickel; Phase Equilibria; Scandium; System

1. Introduction

For the investigation of the phase equilibria of the Sc–Ti–Ni ternary system some alloys of the Sc–Ni binary boundary system were also prepared. However, in the course of the study of the Sc–Ti–Ni system there was some disagreement with the known composition of the Sc–Ni system in the alloy range > 50 at.% Sc [1]. In addition, there is a lack of data for scandium-rich alloys [1]. Therefore, a reinvestigation of the binary Sc–Ni system in the range up to 50 at.% Ni was undertaken.

Sc–Ni alloys have been investigated previously [2]. Five intermediate phases, $ScNi_5$ (ξ), Sc_2Ni_7 (ν), $ScNi_2$ (λ_2), ScNi (δ) and Sc_2Ni (η), were found and their crystal structures ($CaCu_5$, Ce_2Ni_7, $MgCu_2$, CsCl and Ti_2Ni-type, respectively) were determined in addition to the interaction between them. The solubility of scandium in nickel has also been investigated [1,3]. Partial phase diagrams of the system have been proposed in the ranges < 80 at.% Sc [1] and < 40 at.% Sc [3]. The results for the former range confirm those for the latter.

The phase diagram of the Sc–Ni system reported in Ref. [2] is not a compilation of data from Refs. [1,3,4] and is based on data from Ref. [1] exclusively.

2. Experimental details

The alloys (12 compositions) were melted from scandium (98 wt.%) and nickel (99.99 wt.%) in an arc furnace with a non-consumable W electrode on a water-cooled copper bottom. The weight losses on melting were generally about 2 wt.%. After preliminary homogenisation at subsolidus temperature the alloys were annealed at 950°C (in 0–53 at.% Sc) and 750°C (50–100 at.% Sc) in an argon atmosphere. Taking into consideration the similar volatilities of scandium and nickel the losses were attributed to both scandium and nickel. Since the deviations in the composition of the alloys were observed to be < 1.5 wt.% according to chemical analysis they were accepted as nominal values. The oxygen content of remelted scandium was 1.34 wt.% by chemical analysis.

The investigation was carried out by means of metallographic, X-ray, differential thermal (method errors ~ 1%) and electron microprobe analyses.

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0925-8388/97/$17.00
PII S0925-8388(97)00467-2

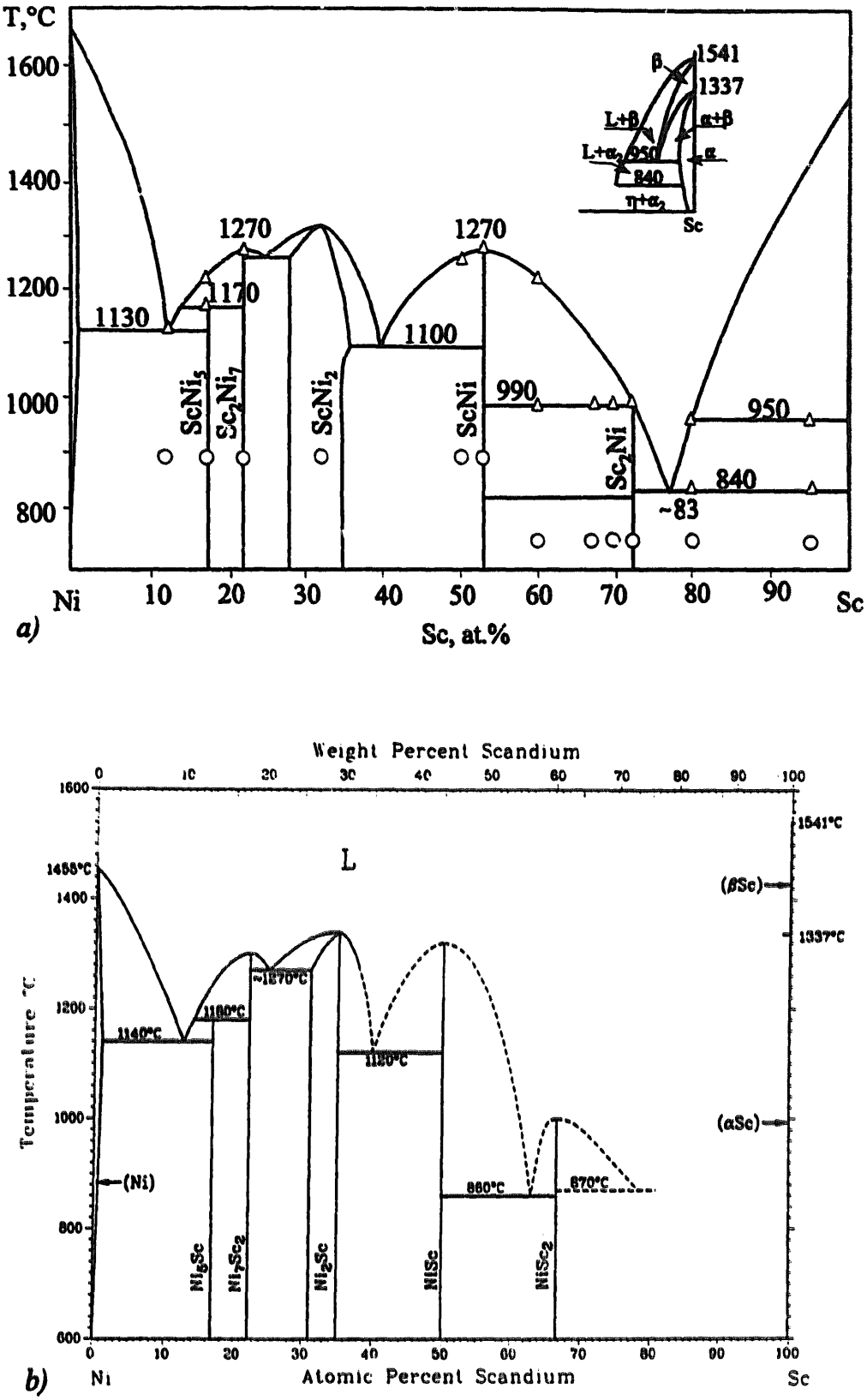

Fig. 1. The Sc–Ni System: (a) present data, (b) from Massalski [2]. (○) Composition of alloy, (△) DTA data.

3. Results and discussion

The results of the investigation are presented in Figs. 1–3. The lattice parameters of all phases as well as other physical-chemical analyses data are shown in Table 1.

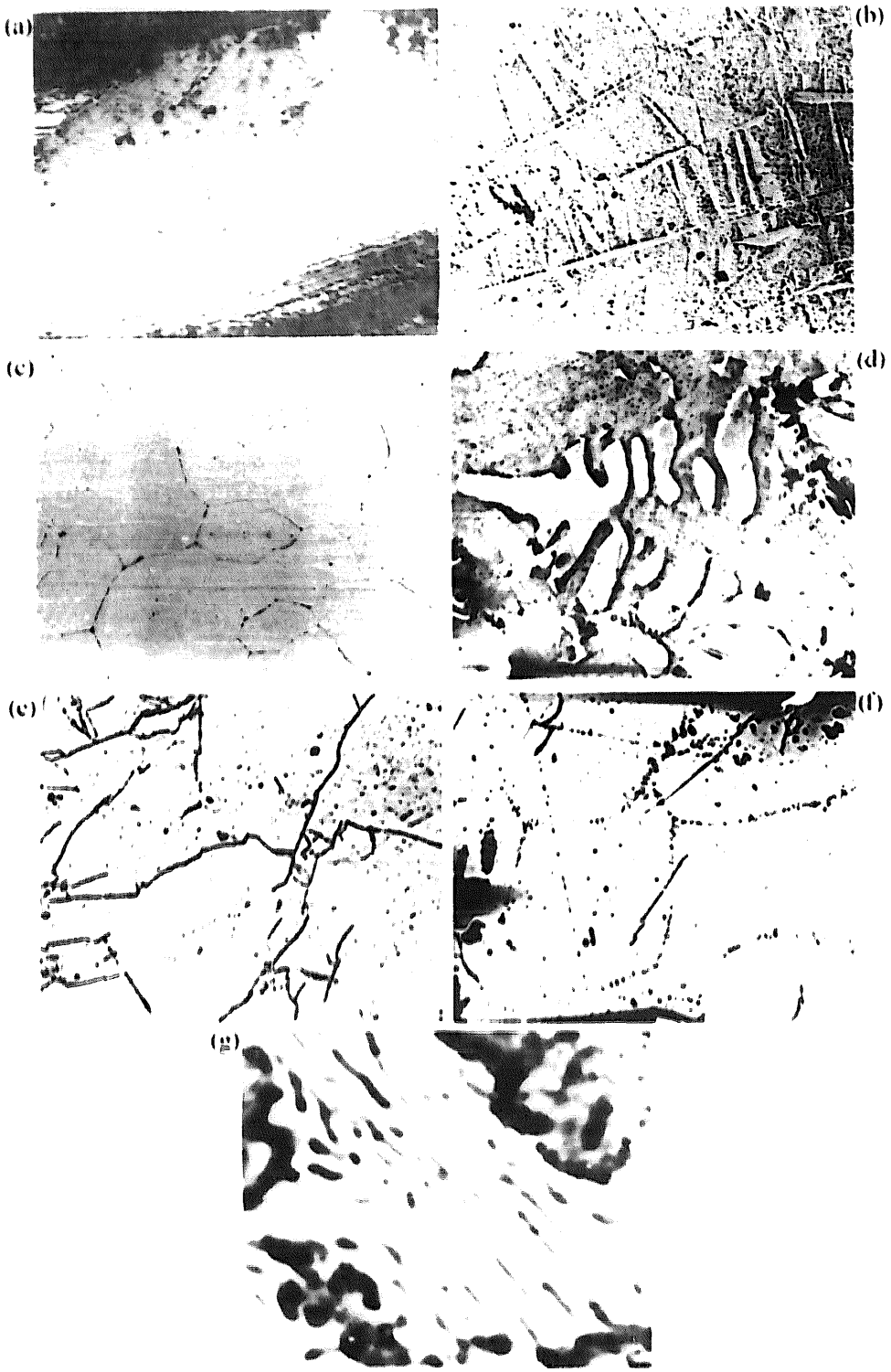

Fig. 2. Microstructure of some alloys of the Sc–Ni system: (a) 88Ni-12Sc, as-cast, ×500, eutectic ($\gamma + \xi$); (b) 83.3Ni-16.7Sc, annealed at 950°C, ×750, ξ; (c) 77.8Ni-22.2Sc, annealed at 950°C, ×500, ν; (d) 32Ni-68Sc, as-cast, ×1000, δ; (e) 32Ni-68Sc, annealed at 750°C, ×400, $\delta + \eta$; (f) 28Ni-72Sc, annealed at 750°C, ×600, η; (g) 20Ni-80Sc, as-cast, ×4000, eutectic ($\eta + \alpha_{Sc}$).

The mutual solubility of components was found to be < 0.6 at.%.

Our data for the melting temperatures of the ν- and λ_2-phases, the method and temperature of formation of the ξ-phase, and the homogeneity range of the Laves phase concur, in general, with those presented in Refs. [1,3,4] and confirm the constitution of the Sc–Ni binary phase diagram in the 0–50 at.% Sc range presented in Ref. [2]. Differences are associated with the temperature fix for some nonvariant equilibria. The solidus temperatures of the two-phase $\gamma + \xi$, $\nu + \xi$ and $\lambda_2 + \delta$ alloys based on our data were found to be 1125, 1170 and 1100°C, respectively, and are in agreement with data reported in Ref. [1] within the

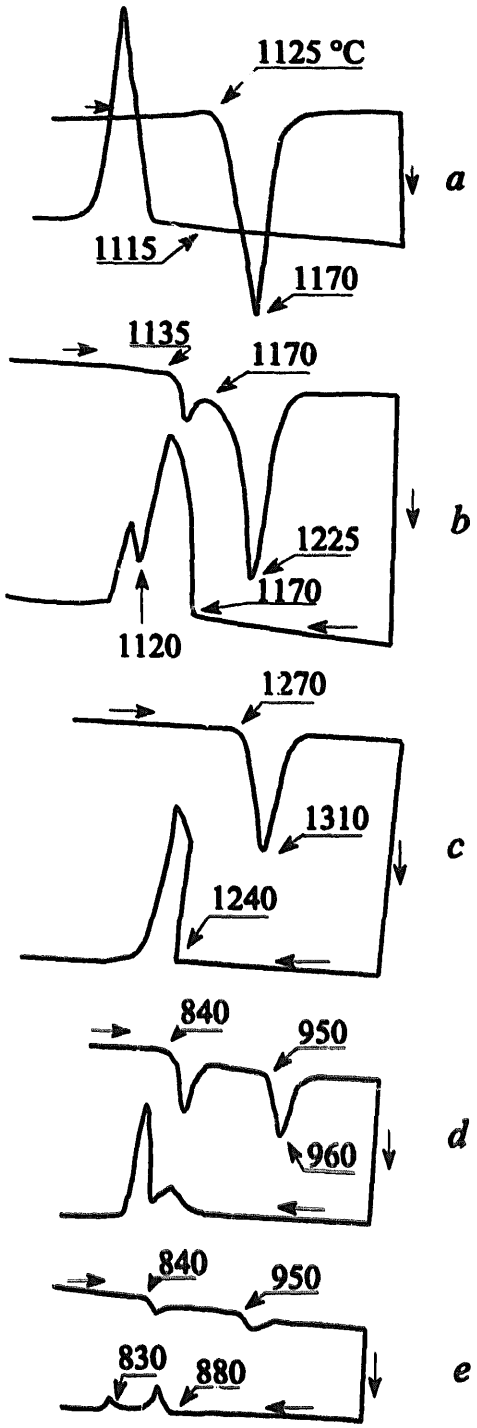

Fig. 3. Differential thermal analysis data for alloys: (a) 88Ni-12Sc, annealed at 1050°C, 12 h; (b) 83.3Ni-16.7Sc, as-cast; (c) 77.8Ni-22.2Sc, as-cast; (d) 20Ni-80Sc, as-cast; (e) 5Ni-95Sc, as-cast.

errors of the DTA method. The microstructure and thermal curve of the cast alloy with 12 at.% Sc (Fig. 2a, Fig. 3a) confirm that the $L \rightleftarrows \gamma + \xi$ eutectic reaction takes place. The ξ-phase is formed at 1170°C (Fig. 3b) via the peritectical reaction $L + \nu \rightleftarrows \xi$. Its microstructure with the martensitic transformation signs is shown in Fig. 2b. The ν-phase was crystallised from the melt at 1270°C (Fig. 3c). The microstructure of the annealed alloy of stoichiometric composition (Fig. 2c) does not reveal polymorphism in this phase, which agrees with Ref. [3]. The ξ-, ν- and δ-phases have a restricted homogeneity range (< 1 at.%). As reported from the investigation of the Sc–Ti–Ni ternary system [5] the λ_2-phase has a homogeneity range of about 7%, from 28 to 35 at.% Sc.

Data for the alloys in the range 50–100 at.% Sc suggest a phase diagram that differs from the fragment presented in Ref. [2]. The η-phase is found to be formed via the peritectical reaction $L + \delta \rightleftarrows \eta$ at 990°C. The microstructure of the cast alloy with 68 at.% Sc, where dendrites of the δ-phase are clearly evident (Fig. 2d), testifies to this fact. There are two phases ($\delta + \eta$) for both the cast and annealed state (Fig. 2e) in this alloy. No homogeneity range of η-phase exists. The composition (72 at.% Sc) deviates from the 1:2 stoichiometry in favor of the alloys containing more scandium. The same behaviour is observed for the equiatomic phase. Its composition is 53 at.% Sc. The compositions of the liquid taking part in the peritectical reaction and of the η-phase are similar. The latter is on the edge of the peritectical horizontal.

It should be mentioned that the thermal effect on heating and cooling at ~ 830°C for alloys of the $\delta + \eta$ two-phase range, which has been attributed to the eutectic reaction $L \rightleftarrows \delta + \eta$ at 860°C [1], was also observed here. However, additional study of its nature showed that it is not associated with the alloy melting process. Metallographic analysis of the samples heated to 830°C and then cooled showed that a liquid phase did not develop; this has nothing to do with the eutectic reaction at this temperature and may be caused by impurities of scandium.

The data obtained for Sc_2Ni formation are in reasonable agreement, not only with our characterised Sc–Ni–Ti ternary system, but also concur with the regularity of the change in topology of the phase diagrams of the binary alloys formed by metals with similar metallochemical properties. The Ti–Ni, Zr–Ni and Hf–Ni phase diagrams [2] show that the phases of A_2B composition are formed as follows: Ti_2Ni by peritectical reaction at 990°C; Zr_2Ni and Hf_2Ni crystallise from the melt at 1140 and 1220°C, respectively. Thus along the Ti → Zr → Hf row the thermal stability of the A_2B phase is shown to increase. This correlates with the thermodynamic stability of these compounds: $\Delta H_f = -29.3 \pm 0.5$ (Ti_2Ni), $\Delta H_f = -36.8 \pm 1$ (Zr_2Ni) and $\Delta H_f = -36.7 \pm 1.3$ (Hf_2Ni) kJ/g.at [6]. No experimental data for the enthalpy of formation of Sc_2Ni were available, but values of $\Delta H_f = -41$ kJ/g.at (Sc_2Ni) and $\Delta H_f = -56$ kJ/g.at (ScNi) were obtained by calculation [7]. We suspect that these values are too high. Using $\Delta H_f = -44.7 \pm 2.3$ kJ/g.at (ScNi) [8], the expected enthalpy value of

Table 1
Phase compositions of Sc–Ni alloys

Alloy composition (at.%)		Thermal treatment	Phase composition	$T_{sol.}$ (°C)	Lattice parameter (Å)										
					γ	ξ		ν		λ_2	δ	η	α_{Sc}		
Ni	Sc				a	a	c	a	c	a	a	a	a	c	
88	12	1050, 900	$\gamma + \xi$	1125	3.510	4.730	3.740								
83.3	16.7	950, 900	$\xi + (\gamma)$*	1135, 1170		4.745	3.750								
77.8	22.2	950, 900	ν	1270				4.750	22.72						
50	50	900	$\delta + \lambda_2$	1055						6.920	3.170				
47	53	950, 900	$\delta + \lambda_2$	1250						6.910	3.170				
40	60	750	$\delta + \eta$	995							3.171	12.15			
33	67	750	$\delta + \eta$	990							3.173	12.17			
32	68	830, 750	$\delta + \eta$	985							3.165	12.12			
28	72	830, 750	η	995								12.15			
20	80	750	$\alpha_{Sc} + \eta$	840, 950								12.14	3.296	5.235	
5	95	As-cast		840, 950											

* Small amount of phase

Sc_2Ni is about -20 kJ/g.at, which would correlate with the Sc–Ni phase diagram presented in Fig. 1a.

The $\alpha \rightarrow \beta$ transformation for the scandium based alloys is found to occur via the metatectical reaction, $\beta \rightleftarrows L + \alpha$ (where α is the hpc and β the bcc modifications of scandium), at 950°C, then on further cooling the eutectic reaction, $L \rightleftarrows Sc_2Ni + \alpha_{Sc}$, follows at 840°C (Fig. 2g). On the thermal DTA curves for alloys with 80 and 95 at.% Sc two effects were observed at 950 and 840°C (Fig. 3d,e) corresponding to these transformations.

The Sc–Ni phase diagram was constructed in conformity with the foregoing results.

4. Conclusions

On conducting a systematic investigation of the interactions in ternary systems containing the binary Ti–Ni system we were compelled to revise the phase equilibria of the Sc–Ni system since there was only a fragmentary phase diagram available and this contained some discrepancies with our data in a known part of the system for the ternary Sc–Ti–Ni system.

The new features characterising the binary Sc–Ni system are: Sc_2Ni is formed by peritectical reaction $L + \delta \rightleftarrows \eta$ at 990°C, the solid solution based on β-Sc undergoes the metatectical reaction $\beta \rightleftarrows L + \alpha$ at 950°C and a eutectic reaction takes place between the most scandium-rich intermediate phase and the α-Sc based solid solution at 840°C.

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