Influence of Addition of Nickel on the Thermal Expansion, Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt, Iron and Chromium, Especially of Co-Elinvar. II : Additions of 30 and 40 per cent of Nickel

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Influence of Addition of Nickel on the Thermal Expansion, Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt, Iron and Chromium, Especially of Co-Elinvar. II

Additions of 30 and 40 per cent of Nickel*

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Synopsis

The influence of additions of 30 and 40 per cent of nickel on the thermal expansion in the range from 10 to 50°, rigidity modulus at 20° and its temperature coefficient in the range from 20 to 50° of the alloys of cobalt, iron and chromium was studied. The relations between those properties and the concentrations of nickel-added alloys were almost similar qualitatively to those in the case of the ternary alloys of cobalt, iron and chromium, that is, there were two groups of alloys, one showing a positive temperature coefficient of rigidity modulus and the other a negative. And it has been found that the content of cobalt at the composition showing the smallest value of the coefficient of thermal expansion and the largest positive maximum of the temperature coefficient of rigidity modulus decreases with the increase of nickel content and finally reaches zero at the composition of invar in the binary system of nickel and iron, while the content of chromium does not change until that of nickel reaches about 15 per cent, then gradually decreases and becomes zero at the composition of about 30 per cent of nickel and the rest of iron. In the case of addition of 30 per cent of nickel, the smallest thermal expansion coefficient was 1.87×10^{-6}, while in the case of addition of 40 per cent, it was 0.54×10^{-6}. The largest positive values of the temperature coefficient of rigidity modulus in the corresponding cases were respectively $+76.4\times10^{-5}$ and $+81.0\times10^{-5}$. The largest and smallest values of rigidity modulus in the case of addition of 30 per cent of nickel were 7.84×10^5kg/cm^2 and 4.55×10^5kg/cm^2, and in the case of 40 per cent of nickel they were respectively 8.96×10^5kg/cm^2 and 4.69×10^5kg/cm^2.

I. Introduction

One of the present authors(1) proposed previously a rule on the small expansibility of invar. Deducing the rule, two of them(2) in 1942 invented a new elinvar-type alloy "Co-elinvar", an alloy of cobalt, iron and chromium. Since then, they also studied with another author(3) on the influence of additions of 10 and 20 per cent of nickel on physical properties of co-elinvar and found that the concentration

* The 815th report of the Research Institute for Iron, Steel and Other Metals. Read at the spring and the autumn meetings of the Japan Institute of Metals, April 1 and Oct. 10, 1951 and published in the Journal of the Institute (Nippon Kinzoku Gakkai-Si), **18** (1954), 81.

(1) H. Masumoto, Sci. Rep., Tôhoku Imp. Univ., **20** (1931), 101; Kinzoku no Kenkyû, **8** (1931), 237.

(2) H. Masumoto, and H. Saitô, Nippon Kinzoku Gakkai-Si, **6** (1942), 122; **8** (1944), 513; **16** (1952), 125; Sci. Rep., RITU, **A1** (1949), 17; **4** (1952), 246.

(3) H. Masumoto, H. Saitô and T. Kôno, Nippon Kinzoku Gakkai-Si, **17** (1953), 255; Sci. Rep., RITU, **A6** (1954), 529.

range having positive value of the temperature coefficient of rigidity modulus became wider with an addition of nickel and, therefore, there being much alloys of elinvar-type than in the case of the ternary system, and that the change of the coefficient to the concentration became smaller with an increase of nickel content. Thus, the present authors studied on the influence of more addition of nickel on the thermal expansion, rigidity modulus and its temperature coefficient of the ternary alloys of cobalt, iron and chromium. In the following lines, the results in the cases of the additions of 30 and 40 per cent of nickel will be described.

II. Specimens and method of measurement

The materials used for the preparation of alloys, the methods of melting, manufacturing and heat treatment of the specimens, and the measuring apparatuses are the same as those in the Part I of this paper(3).

The compositions of the alloys used are given in Tables 1 and 2.

III. Results of measurement

The results of measurement of the alloys of cobalt, iron and chromium to which 30 and 40 per cent of nickel were added, that is, of the alloys of the quaternary

Table. 1. Composition of the Co-Fe-Cr alloys with an addition of 30 per cent of nickel and the results of measurement.

Composition (%)				G (kg/cm^2)	α	g	Composition (%)				G (kg/cm^2)	α	g
Co	Fe	Cr	+Ni	(20°)	(10∼50°)	(20∼50°)	Co	Fe	Cr	+Ni	(20°)	(10∼50°)	(20∼50°)
				$\times 10^5$	$\times 10^{-6}$	$\times 10^{-5}$					$\times 10^5$	$\times 10^{-6}$	$\times 10^{-5}$
10	90	0	30	6.16	10.58	−22.2	11	79	10	30	6.88	15.15	−23.2
20	80	0	30	6.06	10.93	−28.0	15	75	10	30	6.64	10.65	− 9.8
24	76	0	30	6.16	11.12	−19.9	19	71	10	30	6.69	5.31	+22.6
30	70	0	30	6.16	11.82	−24.6	25	65	10	30	6.37	4.90	+27.4
35	65	0	30	5.93	11.92	−25.3	30	60	10	30	6.41	6.47	+16.1
40	60	0	30	4.79	12.38	+10.0	34	56	10	30	6.14	7.50	+ 5.8
44	56	0	30	5.37	10.54	+ 8.7	40	50	10	30	6.32	9.26	− 6.3
50	50	0	30	6.14	11.64	−19.5	45	45	10	30	6.35	9.96	−14.1
55	45	0	30	5.83	11.90	−21.3	50	40	10	30	6.59	11.39	−21.6
15	82	3	30	5.75	10.83	−25.3	36	51	13	30	6.61	8.10	− 0.3
20	77	3	30	5.72	10.59	−25.3	13	73	14	30	6.98	13.70	−29.8
25	72	3	30	5.55	10.08	−22.1	17	69	14	30	6.94	11.12	−14.0
32	65	3	30	5.40	8.25	+18.1	21	65	14	30	7.12	8.20	+ 5.9
37	60	3	30	4.55	9.12	+10.2	26	60	14	30	6.97	6.40	+14.5
41	56	3	30	5.20	9.78	+12.1	30	56	14	30	6.59	7.19	+ 4.8
44	53	3	30	5.48	10.65	− 3.2	41	45	14	30	6.37	9.04	− 3.5
10	84	6	30	6.98	15.52	−32.5	45	41	14	30	6.89	9.08	−13.0
13	81	6	30	6.67	12.56	−10.6	48	38	14	30	6.81	9.11	−16.8
17	77	6	30	6.57	3.83	+39.8	33	50	17	30	7.11	9.33	− 5.0
20	74	6	30	6.28	2.54	+62.7	38	45	17	30	6.94	9.10	− 6.9
21	73	6	30	5.88	1.87	+76.4	10	70	20	30	7.23	16.60	−38.6
25	69	6	30	5.26	3.63	+61.7	14	66	20	30	7.39	15.39	−36.9
29	65	6	30	5.39	4.75	+46.6	20	60	20	30	7.84	15.20	−37.6
34	60	6	30	5.65	6.14	+28.4	24	56	20	30	7.36	14.01	−34.4
38	56	6	30	5.84	8.77	+10.5	30	50	20	30	7.48	11.57	−21.0
44	50	6	30	6.08	10.40	− 6.8	35	45	20	30	7.19	10.32	− 8.0
49	45	6	30	6.52	11.02	−22.8	45	35	20	30	7.44	10.52	− 6.7
18	74	8	30	6.37	4.18	+39.9							

Table. 2. Compositon of the Co-Fe-Cr alloys with an addition of 40 per cent of nickel and the results of measurement.

Composition (%)				G (kg/cm^2) (20°)	α (10~50°)	g (20~50°)
Co	Fe	Cr	+Ni	$\times 10^5$	$\times 10^{-6}$	$\times 10^{-5}$
0	100	0	40	6.32	13.61	−20.8
4	96	0	40	6.40	9.11	− 4.6
11	89	0	40	5.83	8.02	+10.8
15	85	0	40	5.62	8.36	+14.9
20	80	0	40	4.82	4.47	+50.3
25	75	0	40	4 69	6.60	+28.8
30	70	0	40	5.05	8.74	+ 5.4
35	65	0	40	5.08	9.97	− 6.5
40	60	0	40	5.52	10.84	− 8.1
45	55	0	40	5.83	12.22	−14.3
65	35	0	40	6.11	12.07	−27.6
0	98	2	40	7.97	14.55	−23.3
2	96	2	40	8.09	9.32	+14.9
7	91	2	40	6.72	3.05	+55.6
9	89	2	40	5.98	1.56	+63.7
11	87	2	40	5.92	0.54	+78.3
13	85	2	40	5.01	1.04	+81.0
15	83	2	40	5.03	1.37	+77.4
17	81	2	40	4.82	2.53	+55.4
0	96	4	40	8.96	13.77	−18.3
3	93	4	40	7.93	9.70	+ 7.3
7	89	4	40	7.26	4.00	+47.4
11	85	4	40	6.78	1.84	+51.4
13	83	4	40	6.77	1.58	+56.6
15	81	4	40	5.92	2.26	+62.3
17	79	4	40	5.74	2.92	+59.4
20	76	4	40	5.50	4.29	+39.8
23	73	4	40	5.39	5.98	+24.1
26	70	4	40	5.32	7.53	+ 7.5
31	65	4	40	5.75	8.91	− 0.9
36	60	4	40	5.92	10.09	− 7.6
43	53	4	40	5.74	11.34	−17.2
5	89	6	40	6.34	7.18	+ 4.9
8	86	6	40	6.49	5.22	+31.7
11	83	6	40	6.96	2.79	+41.5
13	81	6	40	6.78	2.98	+39.1
15	79	6	40	6.54	3.08	+49.1
17	77	6	40	6.18	3.49	+45.4
0	93	7	40	7.41	14.23	−27.0

Composition (%)				G (kg/cm^2) (20°)	α (10~50°)	g (20~50°)
Co	Fe	Cr	+Ni	$\times 10^5$	$\times 10^{-6}$	$\times 10^{-5}$
3	89	8	40	7.81	11.32	−14.6
9	83	8	40	6.49	6.14	+25.9
11	81	8	40	6.60	4.69	+29.2
13	79	8	40	6.28	4.03	+29.4
15	77	8	40	6.29	4.21	+32.3
17	75	8	40	6.29	4.12	+36.9
20	72	8	40	5.48	5.50	+28.5
0	90	10	40	8.22	14.88	−30.3
3	87	10	40	7.00	12.81	+ 2.5
7	83	10	40	6.68	7.55	+16.2
9	81	10	40	7.15	6.09	+23.5
11	79	10	40	6.02	4.97	+26.8
13	77	10	40	7.19	5.47	+25.0
15	75	10	40	7.07	4.58	+23.3
20	70	10	40	6.18	5.35	+21.3
25	65	10	40	6.40	7.01	+ 9.7
30	60	10	40	6.26	9.00	− 2.9
40	50	10	40	6.14	10.83	−16.9
4	85	11	40	7.39	9.67	+ 9.6
0	87	13	40	8.20	15.21	−33.9
7	80	13	40	7.54	9.53	+ 5.4
10	77	13	40	7.80	8.86	+ 7.5
12	75	13	40	7.80	7.64	+ 9.3
2	83	15	40	8.19	14.30	−34.2
4	81	15	40	7.99	13.12	−27.4
8	77	15	40	8.14	12.94	−21.6
15	70	15	40	7.03	7.62	+10.0
20	65	15	40	6.77	8.09	+ 4.3
25	60	15	40	6.87	8.31	+ 0.9
30	55	15	40	6.69	8.97	− 6.6
35	50	15	40	6.59	10.44	− 8.7
0	80	20	40	7.60	16.57	−40.0
5	75	20	40	7.29	15.75	−35.9
10	70	20	40	7.37	13.19	−29.3
15	65	20	40	6.82	11.78	−19.5
20	60	20	40	6.82	10.66	− 9.7
25	55	20	40	6.76	9.96	− 8.3
30	50	20	40	6.52	10.08	− 6.9
35	45	20	40	6.76	9.63	− 5.9

system of cobalt, iron, chromium and nickel containing 23.1 per cent and 28.6 per cent of nickel are given in Tables 1 and 2. In the tables, G is the rigidity modulus at 20°, α the mean linear expansion coefficient in the range from 10 to 50° and g the mean temperature coefficiont of rigidity modulus in the range from 20 to 50°. These results are graphically shown in Figs. 1, 2 and 4 to 7, in which the projection planes represent the concentrations of cobalt, iron and chromium in ternary system.

1. Linear expansion coefficient

As seen in Figs. 1 and 2, in the case of the addition of 30 per cent of nickel the mean linear expansion coefficient in the range from 10 to 50° showed its smallest value of 1.87×10^{-6} in the alloy containing 21 per cent of cobalt, 73 per cent of iron and 6 per cent of chromium; and in the case of the addition of 40 per cent

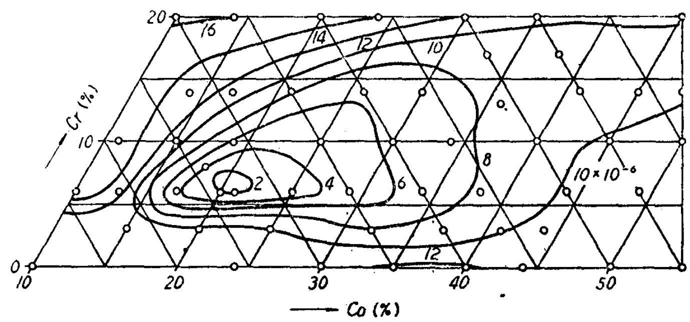

Fig. 1. Thermal expansion coefficient of Co-Fe-Cr alloys added with 30 per cent of nickel.

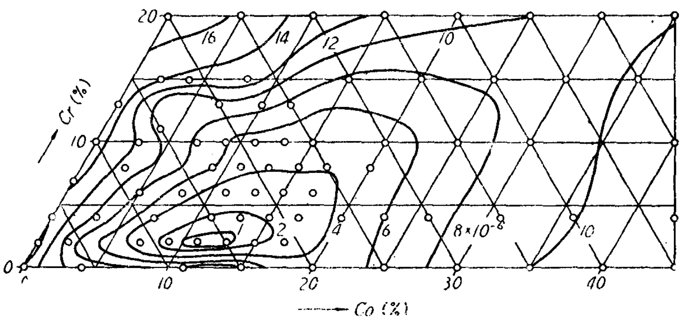

Fig. 2. Thermal expansion coefficient of Co-Fe-Cr alloys added with 40 per cent of nickel.

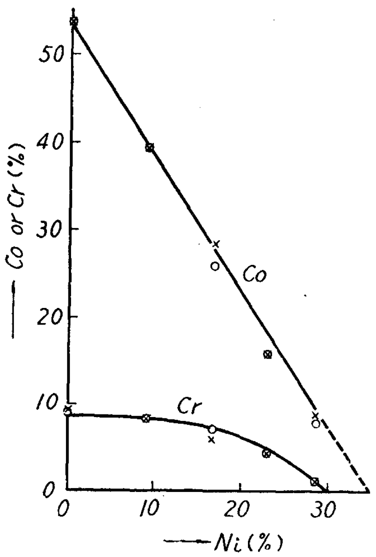

Fig. 3. Relations between the contents of Co or Cr and Ni in the compositions at the minimum of thermal expansion (○) or the maximum of the positive value of the temperature coefficient of rigidity modulus(×).

of nickel the smallest value of 0.54×10^{-6} in the alloy containing 11 per cent of cobalt, 87 per cent of iron and 2 per cent of chromium, while as the concentrations of the alloys went away from those compositions mentioned above, the coefficient increased first rapidly and then gradually, and became one of the usual order larger than 10×10^{-6}.

Comparing these results with those of the ternary alloys of cobalt, iron and chromium previously obtained by one of the present authors[4] (see Fig. 3 in Part I[3]) and those of the alloys with additions of 10 and 20 per cent of nickel[3] (Figs. 1 and 2 in Part I), it can be seen that the figures of the iso-thermal expansion coefficient curves are almost similar to each other, that the change of the expansion coefficient with the concentrations in the range of high cobalt content becomes smaller with the increase of nickel content, and further that the composition of stainless-invar, 54 per cent of cobalt, 37 per cent of iron and 9 per cent of chromium, which shows the smallest thermal expansion in the ternary system, shifts to the side of low cobalt content with the addition of nickel. In Fig. 3, the relations between content of cobalt or chromium and that of nickel at the compositions showing the smallest thermal expansion are shown with circles. As seen in the figure, the content of cobalt at the composition of stainless-invar can almost linearly be substituted by nickel: The content of cobalt decreases with the increase of nickel content and finally reaches zero at the composition of invar in the binary system of nickel and iron. The content of chromium does not change until that of nickel reaches about

(4) H. Masumoto, Sci. Rep., Tôhoku Imp. Univ , **23** (1934), 265 ; Nippon Kinzoku Gakkai-Si, **2** (1938), 141.

15 per cent, then gradually decreases and becomes zero at the composition of about 30 per cent of nickel and the rest of iron.

2. Rigidity modulus

The relations between the rigidity modulus at 20° and the concentrations in the case of the additions of 30 and 40 per cent of nickel to the cobalt, iron and chromium alloys are shown respectively in Figs. 4 and 5. Comparing these results with those of the ternally alloy(2) (Fig. 6 in Part I) and of the alloys added by 10 and 20 per cent of nickel(3) (Figs. 4 and 5 in Part I), it can be seen that they are qualitatively similar to each other. In the case of the ternary alloy, there was a valley running from the composition of about 83 per cent of cobalt, about 17 per cent of iron and 0 per cent of chromium to that of about 50 per cent of cobalt, about 41 per cent of iron and about 9 per cent of chromium. When 30 per cent of nickel was added to the ternary alloy, a valley similar to that in the ternary system ran from the composition of about 40 per cent of cobalt, about 60 per cent of iron and 0 per cent of chromium to that of about 10 per cent of cobalt, about 88 per cent of iron and about 2 per cent of chrhmium, while in the case of 40 per cent addition of nickel, a similar valley archwise ran from the composition of about 25 per cent of cobalt, about 75 per cent of iron and 0 per cent of chromium to that of about 5 per cent of cobalt, about 95 per cent of iron and 0 per cent of chromium. Thus, as the nickel content becomes higher, the valley shifts to the side of low cobalt and low chromium, and simultaneously, the modulus generally becomes smaller. But, in this case, we can not find a clear relation between contents of nickel and other elements in the quaternary system.

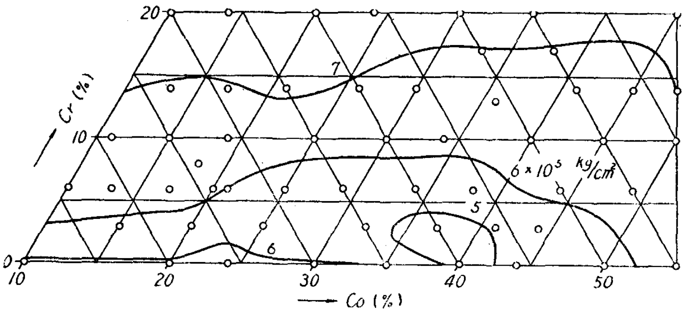

Fig. 4. Rigidity modulus of Co-Fe-Cr alloys added with 30 per cent of nickel.

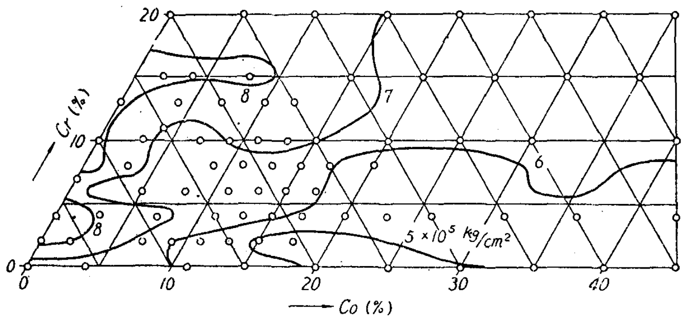

Fig. 5. Rigidity modulus of Co-Fe-Cr alloys added with 40 per cent of nickel.

The largest and smallest values of rigidity modulus in the case of 30 per cent addition of nickel were respectively $7.84 \times 10^5 kg/cm^2$ in the alloy containing 20 per cent of cobalt, 60 per cent of iron and 20 per cent of chromium and $4.55 \times 10^5 kg/cm^2$ in the alloy containing 37 per cent of cobalt, 60 per cent of iron and 3 per cent of chromium; in the case of 40 per cent addition of nickel, they were respectively $8.96 \times 10^5 kg/cm^2$ in the alloy containing 0 per cent of cobalt, 96 per cent of iron and 4 per cent of chromium and $4.69 \times 10^5 kg/cm^2$ in the alloy containing 25 per cent of cobalt, 75 per cent of iron and 0 per cent of chromium.

3. Temperature coefficient of rigidity modulus

The temperature coefficients of rigidity modulus in the range from 20 to 50° in two series of the alloys are graphically shown in Figs. 6 and 7. As seen in the figures, the coefficients were generally negative and of the usual order larger than -20×10^{-5}, while as the concentrations of the alloys approached the compositions showing the respective smallest values of thermal expansion coefficient mentioned above, the temperature coefficient of the modulus diminished first gradually and then rapidly, and changed its sign after becoming zero at a certain concentration. Then the coefficient, in the case of 30 per cent of nickel, reached the largest positive value, $+76.4\times10^{-5}$, at the composition of 21 per cent of cobalt, 73 per cent of iron and 6 per cent of chromium; in the case of 40 per cent of nickel, the largest positive value, $+81.0\times10^{-5}$, at the composition of 13 per cent of cobalt, 85 per cent of iron and 2 per cent of chromium. That is, the temperature coefficient of rigidity modulus showed its largest positive value almost at the composition showing the smallest value of thermal expansion coefficient.

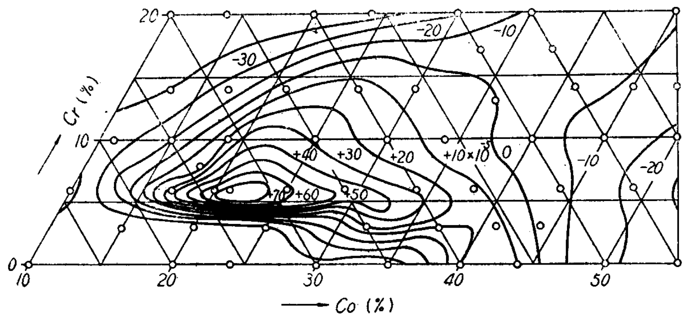

Fig. 6. Temperature coefficient of rigidity modulus of Co–Fe–Cr alloys added with 30 per cent of nickel.

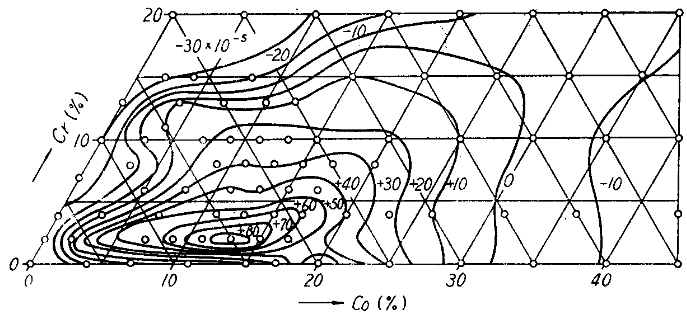

Fig. 7. Temperature coefficient of rigidity modulus of Co–Fe–Cr alloys added with 40 per cent of nickel.

These results are almost similar to those of the plain ternary alloy(2) and of the alloys added by 10 and 20 per cent of nickel(3) which were shown in Figs. 9, 7 and 8 in Part 1. And it can be seen that, when nickel content increases, the concentration range showing the positive temperature coefficient of rigidity modulus becomes wider, and the change of the coefficient with the concentration becomes smaller in the range of high cobalt content; resulting a noteworthy fact for an application of co-elinvar to a practical use. Further, the composition showing the largest positive value of the coefficient in the ternary system shifts to the side of low cobalt content with the increase of nickel content. In Fig. 3, the relation between content of cobalt or chromium and that of nickel at the compositions showing the largest positive value of the coefficient is shown with crosses. As seen in the figure, the relations are almost the same as those in the case of thermal expansion mentioned above.

The alloys with a comparatively small temperature coefficient of rigidity modulus are given in Table 3. In the table, the compositions in brackets show

Table. 3. Some examples of co-elinver added with 30 and 40 per cent of nickel

Specimen No.	Composition (%) Co	Fe	Cr	+Ni	G (kg/cm^2) (20°)	α (10~50°)	g (20~50°)
					$\times 10^5$	$\times 10^{-6}$	$\times 10^{-5}$
316	44(33.8)	53(40.8)	3(2.3)	30(23.1)	5.48	10.65	− 3.2
338	36(27.7)	51(39.2)	13(10.0)	30(23.1)	6.61	8.10	− 0.3
343	30(23.0)	56(43.1)	14(10.8)	30(23.1)	6.59	7.19	+ 4.8
344	41(31.5)	45(34.6)	14(10.8)	30(23.1)	6.37	9.04	− 3.5
347	33(25.3)	50(38.5)	17(13.1)	30(23.1)	7.11	9.33	− 5.0
321	21(16.1)	73(56.2)	6(4.6)	30(23.1)	5.88	1.87	+76.4
402	4(2.8)	96(68.6)	0(0)	40(28.6)	6.40	9.11	− 4.6
430	31(22.1)	65(46.4)	4(2.9)	40(28.6)	5.75	8.91	− 0.9
433	5(3.6)	89(63.5)	6(4.3)	40(28.6)	6.34	7.18	+ 4.9
448	3(2.1)	87(62.2)	10(7.1)	40(28.6)	7.00	12.81	+ 2.5
456	30(21.5)	60(42.8)	10(7.1)	40(28.6)	6.26	9.00	− 2.9
467	20(14.3)	65(46.4)	15(10.7)	40(28.6)	6.77	8.09	+ 4.3
468	25(17.9)	60(42.8)	15(10.7)	40(28.6)	6.87	8.31	+ 0.9
416	11(7.9)	87(62.1)	2(1.4)	40(28.6)	5.92	0.54	+78.3

those in the quaternary system of cobalt, iron, chromium, and nickel. These alloys are the so-called co-elinvar, which are useful as the material for the hair spring of watches and clocks, for the helical springs of seismograph and a spring balance, and for the standard vibrator and the diaphragm capsule.

Summary

(1) The mean linear expansion coefficient in the range from 10 to 50°, in the case of 30 per cent addition of nickel to the ternary alloy of cobalt, iron and chromium, showed the smallest value of 1.87×10^{-6} in the alloy containing 21 per cent of cobalt, 73 per cent of iron and 6 per cent of chromium; and in the case of 40 per cent addition of nickel, the smallest value of 0.54×10^{-6} in the alloy containing 11 per cent of cobalt, 87 per cent of iron and 2 per cent of chromium. As the concentrations of the alloys went away from those mentioned above, the coefficient became larger first rapidly and then gradually. Further, the compositions showing the smallest thermal expansion coefficient lineary shifted to the side of low cobalt content with the addition of nickel and finally reached that of invar in the binary system of iron and nickel, while chromium content did not change until the nickel content became comparatively higer, and then decreased.

(2) In the space diagram showing the relation between the rigidity modulus at 20° and the concentration of the alloys to which 30 per cent of nickel was added, a valley existed running from the composition of about 40 per cent of cobalt, about 60 per cent of iron and 0 per cent of chromium to that of about 10 per cent of cobalt, about 88 per cent of iron and about 2 per cent of chromium. In the case of addition of 40 per cent of nickel, a valley ran from the composition of about 25 per cent of cobalt, about 75 per cent of iron and 0 per cent of chromium to that of about 5 per cent of cobalt, about 95 per cent of iron and 0 per cent of chromium. The largest and smallest values of rigidity modulus in

the case of addition of 30 per cent of nickel were respectively 7.84×10^{5}kg/cm^{2} in the alloy containing 20 per cent of cobalt, 60 per cent of iron and 20 per cent of chromium and 4.55×10^{5}kg/cm^{2} in the alloy containing 37 per cent of cobalt, 60 per cent of iron and 3 per cent of chromium. In the case of 40 per cent of nickel, they were respectively 8.96×10^{5}kg/cm^{2} in the alloy containing 0 per cent of cobalt, 96 per cent of iron and 4 per cent of chromium and 4.69×10^{5} kg/cm^{2} in the alloy containing 25 per cent of cobalt, 75 per cent of iron and 0 per cent of chromium.

(3) The mean temperature coefficient of rigidity modulus in the rang from 20 to 50° was generally negative and of the usual order, while as the concentrations approaches the compositions showing the smallest thermal expanision coefficient, the temperature coefficient of the modulus diminished first gradually and then rapidly until its sign changed to positive. Thereafter, the coefficient, in the case of 30 per cent addition of nickel, became large and reached the largest positive value, $+76.4\times10^{-5}$, in the alloy containing 21 per cent of cobalt, 73 per cent of iron and 6 per cent of chromium, and in the case of 40 per cent of nickel, the largest positive value was $+81.0\times10^{-5}$ in the alloy containing 13 per cent of cobalt, 85 per cent of iron and 2 per cent of chromium. Thus, the compositions showing the largest positive coefficient shifted to the side of low cobalt content with the increase of nickel content as in the case of the thermal expansion coefficient and the concentration range of the positive coefficient became wider, and the change in the coefficient with the concentration in the range of high cobalt content became smaller.

(4) Co-elinvar containing nickel showed better mechanical properties than those of the plain ternary alloy of cobalt, iron and chromium.

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