Effects of Chromium and Tungsten Additions on the Characteristic Properties of New High Magnetic Permeability Alloys “Nimalloy” in the System of Nickel and Manganese*

By Hakaru Masumoto**, Yûetsu Murakami**
and Masakatsu Hinai**

Since the discovery of high magnetic permeability alloys “Nimalloy”, a series of experiments has been carried out on the effects of additions of various elements on the properties of Nimalloy, and the highest initial permeability of 76000 and the highest maximum permeability of 441000 have been obtained in the case of Cr additions to Ni-Mn-Fe alloys. In the present investigation, it has been found that with increasing Cr and W additions to Ni-Mn binary alloys the cooling rate at which the highest permeability is attained becomes smaller gradually. Therefore, in most cases, the alloys were slow-cooled from 900°C and further baked for a long time at a temperature below the order-disorder transformation point. With increasing contents of Cr and W, both the initial and maximum permeabilities of the alloys increased gradually to the maximum values and afterwards decreased gradually. By the addition of Cr, the alloy composed of 80.93% Ni, 17.13% Mn and 1.94% Cr showed the highest value of 17000 in initial permeability and the alloy of 80.47% Ni, 17.30% Mn and 2.23% Cr, the highest value of 103000 in maximum permeability. In the case of W addition, the alloy composed of 76.65% Ni, 19.23% Mn and 4.12% W showed the highest values of 13720 in initial permeability and 60700 in maximum permeability.

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I. Introduction

Masumoto et al.⁽¹⁾ discovered previously that Ni-Mn alloys containing less than about 24% Mn exhibits high permeabilities when their ferromagnetic superlattice Ni_3Mn is in optimum ordered state by suitable heat treatments. These alloys were named “Nimalloy”. A series of experiments has ever since been conducted on the variations of the characteristics of Ni-Mn alloys by the addition of $\text{Fe}^{(2)}$, $\text{V}^{(3)}$, $\text{Si}^{(4)}$, $\text{Al}^{(5)}$, $\text{Ti}^{(6)}$, $\text{Sb}^{(7)}$, $\text{Mo}^{(8)}$, $\text{Cr}^{(9)}$, $\text{Sn}^{(10)}$, $\text{W}^{(11)}$, $\text{Co}^{(11)}$, $\text{Cu}^{(11)}$, $\text{Ge}^{(12)}$, $\text{Nb}^{(12)}$ or $\text{Ta}^{(13)}$ as the third element and those of Ni-Mn-Fe alloys by the addition of $\text{Cr}^{(14)}$ or $\text{Mo}^{(15)}$ as the fourth

element. In consequence, the highest initial permeability of 76000 and the highest maximum permeability of 441000 were obtained in the case of Cr additions to Ni-Mn-Fe alloys. Further, from measurements of the saturation magnetostriction $\lambda_s^{(16)-(18)}$ and the crystal magnetic anisotropy energy $K_1^{(19)(20)}$, it has been made clear that both values of λ_s and K_1 are very small in the

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composition range over which the high permeabilities are attained.

The present paper deals with the results of additions of Cr and W to Nimalloy.

II. Specimens and Experimental Procedure

The alloying elements used were electrolytic Ni, electrolytic Mn, 99.8% pure Cr and 99.9% pure W. The former two were the same in purity as those used in the previous work⁽¹⁾. The methods of preparation and measurement were entirely the same as reported previously⁽¹⁾, so that description on them are omitted here. The Ni-Mn-Cr alloy specimens used were 100 kinds in composition of 75.67~97.28% Ni, 0~22.17% Mn and 0.50~6.47% Cr, while the Ni-Mn-W alloy specimens were 90 kinds in composition of 70.29~94.42% Ni, 3.95~23.35% Mn and 1.63~11.87% W.

III. Experimental Results and Consideration

1. Ni-Mn-Cr alloys

The experimental results are summarized in Table 1 and Figs. 1~10. The specimens whose compositions are indicated by solid circles in Figs. 1~2 were heated in vacuum at 900°C for 1 hr and then cooled to room temperature at the specified cooling rates of 9°C/sec, 240°, 10°, 5°, 3° and 0.75°C/hr, respectively. Depending on the kinds of the specimens, some of them were cooled to room temperature at a rate of 5°C/hr and baked at various

temperatures below the order-disorder transformation point. The equi-values curves of these figures are statistically drawn against the alloy composition, using the highest values of μ_0 and μ_m measured at room temperature for each of the alloys examined. It is evident from the figures that by the addition of Cr to Ni-Mn alloys, μ_0 and μ_m increase gradually at the beginning and

Fig. 1 Highest initial permeability in each of Ni-Mn-Cr alloys cooled at various rates from 900°C or further baked at various temperatures

Fig. 2 Highest maximum permeability in each of Ni-Mn-Cr alloys cooled at various rates from 900°C or further baked at various temperatures

Table 1 Magnetic and electric properties of typical Ni-Mn-Cr alloys

Alloy No.	Mn (%)	Cr (%)	Cooling rate from 900°C (°C/hr)	Baking		μ_0	μ_m	$B(G)$ for μ_m	W_h (erg/ cm ³ / cycle)	B_r (G)	H_c (Oe)	$4\pi I_{900}$ (G)	λ_s ($\times 10^{-6}$)	σ ($\mu \Omega$ - cm, 20°C)	α ($\times 10^{-3}$, 0°~ 40°C)	Density (g/cm ³)
				Temperature (°C)	Time (hr)											
33	21.63	—	10	380	50	6860	18000	891	*18.30	*954	*0.0315	2790	—	60.7	0.93	—
35	21.80	—	5	—	—	5090	12490	626	*18.50	*876	*0.0272	2760	0.17	60.5	0.94	8.42
37	22.00	—	10	380	50	5880	20400	908	*19.34	*1052	*0.0270	2804	0.00	60.7	0.93	—
8	19.21	0.84	5	—	—	13030	30200	729	*2.82	*552	*0.0103	—	—	—	—	—
"	"	"	5	400	50	13230	31500	841	—	—	—	—	—	—	—	—
22	17.13	1.94	5	380	600	17000	45000	692	*7.89	*876	*0.0143	3826	0.35	68.1	0.67	—
26	18.15	1.87	5	380	400	11780	54000	1202	—	—	—	4827	0.35	67.2	0.77	8.42
29	18.73	1.75	5	380	400	10780	63400	1975	26.98	2160	0.0247	—	—	—	—	—
33	19.30	1.83	5	400	150	8820	52600	2336	50.87	3340	0.0401	5880	0.70	68.7	0.66	8.34
47	16.34	2.75	5	400	700	9310	86500	1307	32.35	2122	0.0145	4252	0.35	71.0	0.65	—
48	16.82	2.72	5	400	300	10780	58000	1548	*30.88	*1200	*0.0316	4472	0.35	72.0	0.69	8.47
"	"	"	5	400	700	6860	87300	2564	34.49	2135	0.0311	4485	0.35	70.0	0.63	—
49	16.92	2.10	5	400	200	14700	43200	961	*7.45	*1200	*0.0139	3670	0.35	68.5	0.59	—
52	17.30	2.23	0.75	—	—	9800	49500	972	—	—	—	—	—	—	—	—
"	"	"	5	400	400	13170	103000	1843	22.64	2643	0.0168	4550	0.70	73.8	0.31	8.43
"	"	"	5	400	450	14000	101800	2195	20.40	2540	0.0178	4620	0.70	73.2	0.36	—
53	17.31	2.04	5	400	150	13720	47200	1469	*12.31	*908	*0.0155	—	—	—	—	—
59	17.77	2.43	5	400	300	10800	50000	2002	45.92	3350	0.0349	—	—	—	—	—
60	17.79	2.70	5	400	300	10300	60000	1603	37.48	2896	0.0274	4527	0.52	73.3	0.52	—
62	18.04	2.90	5	400	450	5310	91200	2028	—	—	—	—	—	77.4	0.30	—
63	18.25	2.16	5	400	300	9320	83300	2000	27.75	2670	0.0205	4801	1.22	74.8	0.66	—
64	18.73	2.24	5	400	250	7000	72600	2324	31.55	2735	0.0245	5274	1.22	70.7	0.95	8.34
71	15.75	3.42	5	400	450	7350	42000	748	*18.37	*1475	*0.0351	3870	0.70	77.3	0.26	—
72	16.34	3.16	5	400	500	9000	78000	1522	24.39	2283	0.0176	4990	0.35	72.4	0.79	8.42
73	16.55	3.52	5	400	550	5500	45000	1443	40.02	2135	0.0300	4850	1.05	77.8	0.50	8.40
74	16.82	3.19	5	400	400	9500	70500	1628	31.28	2135	0.0180	4460	0.70	74.6	0.37	8.43
75	17.25	3.57	5	420	200	1960	30000	1735	63.20	2255	0.0640	5566	1.75	80.3	0.55	—
87	15.40	4.56	5	420	350	2500	32400	1442	74.80	2670	0.0694	5610	1.05	84.7	0.44	8.47

* $B_m=2000$ G

attain the maxima, and then decrease drastically. The highest values of permeability obtained are 17000 in μ_0 for the alloy composed of 80.93% Ni, 17.13% Mn and 1.94% Cr and 103000 in μ_m for the alloy of 80.47% Ni, 17.30% Mn and 2.23% Cr. These values are by far larger than 6860 in μ_0 and 20400 in μ_m obtained on Ni-Mn binary alloys.

Magnetic and electrical properties of the typical alloys in the Ni-Mn-Cr system are tabulated in Table 1, where W_h is the hysteresis loss, $4\pi I_{900}$ the magnetic induction at an effective field of 900 Oe, σ the electrical resistivity and α the temperature coefficient of resistivity. As shown in the table, the addition of Cr improves greatly the magnetic properties of the Ni-Mn alloys, with a relatively large increase in $4\pi I_{900}$ and σ .

In the case of Ni-Mn-Cr alloys, the cooling rate at which the highest values of μ_0 and μ_m are developed does not show any marked variation against the Cr content in the composition range of more than about 83% Ni, whereas in the composition range of less than about 83% Ni they decrease rapidly with increasing Cr content. Fig. 3 indicates an example of the cooling rate dependence of μ_m for the alloy containing about 80.5% Ni. In the Cr-rich alloys, μ_m does not reach the highest value even if the alloys are subjected to cooling at such a very low rate as 0.75°C/hr. Therefore, in order to maximize μ_m , it is essentially important to advance the ordering of the alloys by means of baking at temperature below the order-disorder transformation point after slow-cooling from a high temperature.

Fig. 3 Effect of cooling rate from 900°C on maximum permeability of Ni-Mn-Cr alloys containing about 80.5% Ni

Fig. 4 illustrates the baking time dependence of μ_0 and μ_m for the same alloy as used in Fig. 3 in case of baking at 400°C after cooling from 900°C at a rate of 5°C/hr. In general, each alloy shows the maximum values of μ_0 and μ_m against the baking time, and the maxima shift toward a longer baking time with increasing Cr content. Fig. 5 shows the baking time dependence of μ_0 and μ_m for No. 52 alloy of the highest maximum permeability (80.47% Ni, 17.30% Mn and 2.23% Cr), when baked at various temperatures after cooling from 900°C at a 5°C/hr. The maximum values of μ_0 and μ_m revealed

Fig. 4 Effect of baking time at 400°C after cooling at 5°C/hr from 900°C on initial and maximum permeabilities of Ni-Mn-Cr alloys containing about 80.5% Ni

Fig. 5 Effect of baking temperature and time after cooling at 5°C/hr from 900°C on initial and maximum permeabilities of 80.47% Ni-17.30% Mn-2.23% Cr alloy

in each curve of the figure shift toward a shorter baking time with rising baking temperature. The highest values of 14000 in μ_0 and 103000 in μ_m were obtained when the alloy was baked at 400°C for 450 and 400 hr, respectively. In Fig. 6, the maximum values of μ_0 and μ_m obtained by baking at 380°, 400° and 420°C after cooling from 900°C at a rate of 5°C/hr are schematically represented as a function of Cr content in the Ni-Mn-Cr alloys containing about 80.5% Ni. Figs. 4, 5 and 6 indicate clearly that there is an optimum baking

temperature and time by which a Ni-Mn-Cr ternary alloy can attain the highest values of μ_0 and μ_m . As can be predicted from the above experimental results on the

Fig. 6 Maximum values of initial and maximum permeabilities obtained by baking at various temperatures after cooling at 5°C/hr from 900°C as a function of Cr content of Ni-Mn-Cr alloys containing about 80.5% Ni

addition of Cr to Ni-Mn alloys, in order to increase the permeability of the alloys, it is necessary to heat them at relatively high temperatures below the order-disorder

Fig. 10 Magnetization and hysteresis curves of No. 52 alloy baked at 400°C for 400 hr after cooling at 5°C/hr from 900°C

Fig. 7 Magnetic induction at an effective field of 900 Oe in Ni-Mn-Cr alloys heat-treated to develop the highest maximum permeability

Fig. 8 Electrical resistivity at 20°C in Ni-Mn-Cr alloys heat-treated to develop the highest maximum permeability

Fig. 9 Magnetic induction and electrical resistivity of Ni-Mn-about 2.7% Cr alloys heat-treated to develop the highest maximum permeability

transformation point after slow cooling from high temperature.

Figs. 7 and 8 show the alloy composition dependence of $4\pi I_{900}$ obtained at $H=900$ Oe and σ at 20°C in each Ni-Mn-Cr alloy heat-treated to develop the highest maximum permeability, and Fig. 9 represents the same relationship in the Ni-Mn-Cr alloys containing about 2.7% Cr. In these figures, the maximum value of $4\pi I_{900}$ appears at the Mn content about 2% lower than the composition $Ni_3(Mn, Cr)$, indicating the advance in the ordering of the alloys. Fig. 10 shows magnetization and hysteresis curves of No. 52 alloy (80.47% Ni, 17.30% Mn, 2.23% Cr) with the highest value of μ_m .

2. Ni-Mn-W alloys

The experimental results on Ni-Mn-W alloys are summarized in Table 2 and Figs. 11~21 corresponding to Table 1 and Figs. 1~10 in the case of Ni-Mn-Cr alloys. It can clearly be understood from Figs. 11 and 12 that with increasing W content, the values of μ_0 and μ_m increase gradually at the beginning, rises to the maxima, and then decrease slowly. And the composition range of high permeabilities is localized on the higher Ni side than the line connecting Ni_3Mn and $Ni_3(Mn, W)$. The highest values of permeabilities obtained are 13720 in μ_0 and 60700 in μ_m for the alloy composed 76.65% Ni, 19.23% Mn and 4.12% W. These values are considerably large as compared with μ_0 and μ_m obtained on Ni-Mn binary alloys. Magnetic and electrical properties of the typical Ni-Mn-W alloys are tabulated in Table 2. As shown in the table, the addition of W to Ni-Mn alloys results in a considerable improvement in μ_0 and μ_m , with a pronounced increase in $4\pi I_{900}$.

Figs. 13 and 14 show the cooling rate dependence of μ_0 and μ_m from 900°C against the Mn content for Ni-Mn-W alloys containing about 4.2% W. In these figures, the values of μ_0 and μ_m exhibit marked variations in the composition range of about 15~21% Mn with the cooling rate. Both values increase steeply with

Table 2 Magnetic and electric properties of typical Ni-Mn-W alloys

Alloy No.	Mn (%)	W (%)	Cooling rate from 900°C (°C/hr)	Baking		μ_0	μ_m	B (G) for μ_m	W_h	B_r	H_c	$4\pi I_{900}$	λ_s	σ	α	Density (g/cm ³)
				Temperature (°C)	Time (hr)				(erg/ cm ³ / cycle)	(G)	(Oe)	(G)	($\times 10^{-6}$)	($\mu \Omega$ - cm, 20°C)	($\times 10^{-3}$, 0°~ 40°C)	
									$B_m=5000$ G			$H=900$ Oe				
20	19.57	2.58	5	—	—	5400	45000	1602	*13.00	*1517	*0.0241	4152	0.17	61.9	0.92	8.61
“	“	“	5	400	60	10150	24400	1522	*9.58	*908	*0.0225	5048	0.17	62.0	1.33	—
22	19.64	2.06	5	400	60	10300	28700	1049	*11.80	*759	*0.0253	5112	0.17	60.8	0.93	8.52
25	20.00	2.91	5	400	30	4500	31650	1550	*58.37	*1292	*0.0347	—	—	64.8	0.89	—
26	20.13	2.08	5	—	—	4500	23500	1046	*20.05	*908	*0.0355	4503	0.35	64.4	0.86	—
35	19.24	3.49	5	400	60	4750	51400	2055	133.61	2817	0.0311	5530	0.35	60.5	1.21	8.65
“	“	“	5	400	180	12980	33400	1630	50.12	1442	0.0356	5694	0.35	58.1	0.87	—
36	19.57	3.83	5	—	—	3960	40900	3645	81.89	3177	0.0452	6243	—	60.7	1.09	—
37	19.90	3.35	5	400	150	10300	37500	1670	62.29	1935	0.0317	5746	0.35	58.9	0.81	8.59
51	18.73	4.80	1.5	—	—	7350	48100	3640	78.40	3940	0.0513	6991	0.52	55.3	1.27	8.76
53	19.12	4.68	1.5	—	—	4900	54900	3420	72.12	4150	0.0460	—	—	—	—	—
54	19.23	4.12	3	—	—	8090	60700	2483	47.47	3160	0.0321	6232	0.35	58.7	0.96	8.74
“	“	“	5	380	280	6620	59400	2376	86.67	3270	0.0342	6159	0.17	59.4	0.91	—
“	“	“	5	380	430	13720	46400	2470	40.94	2030	0.0357	6944	0.35	57.1	1.04	—
57	19.80	4.18	5	380	280	6130	53500	2616	77.99	3254	0.0427	6268	0.35	57.9	0.93	8.72
“	“	“	5	380	430	11250	45700	2643	68.05	3140	0.0389	7498	0.35	55.6	1.13	—
62	17.84	5.34	1.5	—	—	4410	37800	3032	116.10	3670	0.0621	7860	0.70	50.1	1.31	8.74
63	18.73	5.32	1.5	—	—	4410	32700	2830	79.92	3674	0.0580	7350	1.05	55.5	1.21	—
70	16.93	6.45	0.75	—	—	4610	29250	2730	—	—	—	—	—	—	—	—
72	18.21	6.34	0.75	—	—	3920	26200	2560	58.37	4030	0.0812	8087	1.05	52.9	1.16	8.82

* $B_m=2000$ G

Fig. 11 Highest initial permeability in each of Ni-Mn-W alloys cooled at various rates from 900°C or further baked at various temperatures

Fig. 13 Initial permeability of Ni-Mn-about 4.2% W alloys cooled at various rates from 900°C

Fig. 12 Highest maximum permeability in each of Ni-Mn-W alloys cooled at various rates from 900°C or further baked at various temperatures

Fig. 14 Maximum permeability of Ni-Mn-about 4.2% W alloys cooled at various rates from 900°C

decreasing cooling rate and attain the maxima at a cooling rate of 3°C/hr, and then decrease rapidly. The highest values of μ_0 and μ_m obtained are 8090 and 60700 at 19.23% Mn, respectively. With increasing W content, the cooling rate at which the highest values of μ_0 and μ_m are attained decrease gradually in the Ni-Mn-W alloys containing less than about 81% Ni. As an example, Fig. 15 shows the cooling rate dependence of μ_0 and μ_m for the alloys containing about 76% Ni.

Fig. 16 shows the baking time dependence of μ_0 and

Fig. 15 Effect of cooling rate on initial and maximum permeabilities of Ni-Mn-W alloys containing about 76% Ni

Fig. 16 Effect of baking time at 380°C after cooling at a rate of 5°C/hr from 900°C on initial and maximum permeabilities of Ni-Mn-W alloys containing about 76% Ni

μ_m for the same alloys with about 76% Ni subjected to baking at 380°C after cooling from 900°C at a rate of 5°C/hr. In general, the permeability exhibits a maximum against the baking time, and the maximum value shifts toward a longer time with increasing W content. Fig. 17 indicates the baking time dependence of μ_0 and μ_m for No. 54 alloy (76.65% Ni, 19.23% Mn, 4.12% W) when baked at various temperatures after cooling from 900°C at a rate of 5°C/hr. The maximum value in each curve of the figure shifts toward a shorter baking time with increasing baking temperature. The highest values of 13720 in μ_0 and 59400 in μ_m are shown when

Fig. 17 Effect of baking temperature and time after cooling at a rate of 5°C/hr from 900°C on initial and maximum permeabilities of No. 54 (76.65% Ni-19.23% Mn-4.12% W) alloy

Fig. 18 Magnetic induction at an effective field of 900 Oe in Ni-Mn-W alloys heat-treated to develop the highest maximum permeability

Fig. 19 Electrical resistivity at 20°C in Ni-Mn-W alloys heat-treated to develop the highest maximum permeability

Fig. 20 Magnetic induction and electrical resistivity of Ni-Mn-about 4.2% W alloys heat-treated to develop the highest maximum permeability

Fig. 21 Magnetization and hysteresis curves of No. 54 alloy cooled at a rate of 3°C/hr from 900°C

baked at 380°C for 430 and 280 hr, respectively. Thus, an optimum heat treatment is required for an alloy to develop the highest values of μ_0 and μ_m . From the above results on the W addition to Ni-Mn alloys to obtain the highest permeabilities, these alloys must be baked at temperatures below the order-disorder transformation point after slow cooling from a high temperature.

Figs. 18 and 19 show the alloy composition dependence of $4\pi I_{900}$ at $H=900$ Oe and σ at 20°C, respectively, in the Ni-Mn-W alloys heat-treated to develop their highest values of μ_m . The same relationship for the Ni-Mn-W alloys containing 4.2% W is given in Fig. 20. In this figure, the fact that $4\pi I_{900}$ is very large and σ is fairly small at the composition of about 20% Mn indicates that the ordering of the alloys is taking place to some extent. Fig. 21 shows magnetization and hysteresis curves of No. 54 alloy with the highest value of μ_m , when cooled from 900°C at a rate of 3°C/hr.

It has been made clear that like other high permeability alloys, high permeability alloys of the Ni-Mn-Cr and Ni-Mn-W systems, have very small values of λ , as shown in Tables 1 and 2, respectively.

IV. Conclusions

100 kinds of Ni-Mn-Cr alloys composed of 75.67~97.28% Ni, 0~22.17% Mn and 0.50~6.47% Cr and 90 kinds of Ni-Mn-W alloys of 70.29~94.42% Ni, 3.95~23.35% Mn and 1.63~11.87% W were heated in vacuum at 900°C for 1 hr and then cooled at various rates or further baked at temperatures below the order-disorder transformation point depending on the kinds of the alloys examined. The following results were obtained from measurements of their magnetic properties, electrical resistivity and its temperature coefficient at room temperature.

(1) The cooling rate at which the highest permeability is attained in the Ni-Mn-Cr alloys containing less than about 83% Ni and Ni-Mn-W alloys containing less than about 81% Ni becomes smaller with increasing Cr or W contents, respectively.

(2) With increasing Cr or W contents, the values of μ_0 and μ_m increase gradually at the beginning, rises to the maxima, and then decrease gradually. In the case of Ni-Mn-Cr alloys, the highest value of 17000 in μ_0 was obtained on the alloy composed of 80.93% Ni, 17.13% Mn and 1.94% Cr when cooled at a rate of 5°C/hr and baked at 380°C for 600 hr, and the highest value of 103000 in μ_m on the alloys of 80.47% Ni, 17.30% Mn and 2.23% Cr when baked at 400°C for 400 hr after cooling at a rate of 5°C/hr. In the case of Ni-Mn-W alloys, the highest value of 13720 in μ_0 was obtained on the alloy of 76.65% Ni, 19.23% Mn and 4.12% W when baked at 380°C for 430 hr after cooling at a rate of 5°C/hr, and the highest value of 60700 in μ_m on the same alloy when cooled at a rate of 3°C/hr.

(3) The coercive force of Ni-Mn-Cr and Ni-Mn-W alloys is very small in general. The lowest value of coercive force for a maximum magnetic induction of 4000 G is 0.0145 Oe in the alloy composed of 81.91% Ni, 16.34% Mn and 2.75% Cr, with a hysteresis loss of 32.35 erg/cm³/cycle. The lowest value of coercive force for a maximum magnetic induction of 5000 G is 0.0321 Oe in the alloy of 76.65% Ni, 19.23% Mn and 4.12% W, with a hysteresis loss of 47.47 erg/cm³/cycle.

(4) The magnetic induction and electrical resistivity of Ni-Mn-Cr alloys and Ni-Mn-W alloys are large in general. The Ni-Mn-Cr alloy (80.47% Ni, 17.30% Mn and 2.23% Cr) and the Ni-Mn-W (76.65% Ni, 19.23% Mn and 4.12% W) with the highest value of μ_m in the respective systems show 4550 G ($H=900$ Oe) and 73.8 $\mu\Omega\cdot\text{cm}$ (20°C), and 6232 G ($H=900$ Oe) and 58.7 $\mu\Omega\cdot\text{cm}$ (20°C), respectively.

(5) These alloys can more easily be forged and rolled at room and high temperatures than permalloys.