Magnetic Properties of Magnet Alloys of Iron, Wolfram and Molybdenum

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Synopsis

The residual induction and the coercive force of alloys of iron, wolfram and molybdenum system were measured after various heat-treatments. The alloy containing 15 per cent of wolfram and 15 per cent of molybdenum showed the best characteristics when quenched at 1300°C and then annealed at 660°C for 3 hours, that is to say, the residual induction, the coercive force and the maximum energy product amounted respectively to 8600 gauss, 310 oersted and 835,000 gauss-oersted.

I. Introduction

In 1932, W. Köster(1) first studied the mechanical and the magnetic precipitation hardening alloys of iron, cobalt and wolfram system and iron, cobalt and molybdenum system and found that these alloys had excellent properties when used as a magnet. For example, the alloys quenched at 1300°C and then annealed at 600°C have shown the coercive force of 100~350 oersteds and the residual induction of 12,000~6,700 gausses. This magnet is named Remalloy, Comol or others.

Since then, the magnetic characteristics of precipitation hardening alloys have come to be measured with the result that numerous permanent magnets have been invented; among them the M.K. magnet by T. Mishima(2) in 1931 and the N.K.S. magnet by K. Honda and the present investigators in 1933(3) are representative from the practical point of view.

The alloys associated with the above named M.K. or N.K.S. magnet are known as Alnico, Nipermag in America, Alni, Ticonal, Alcomax, Hycomax in England and Oerstit, Boomerang in Germany. These are, however, too expensive because of high contents of nickel and cobalt. The present investigators attempted the measurement on iron, wolfram and molybdenum alloys to get a high class magnet containing neither nickel nor cobalt.

The magnetic characteristics of the two kinds of binary alloys of iron and wolfram, and iron and molybdenum have partly been measured by K.S. Seljester and B.A. Rogers(4). They found the maximum coercive force of 151 oersteds on

* The 845th report of the Research Institute for Iron, Steel and Other Metals. Read at the Committee of the Japan Institute of Metals, Nov. 7, 1947, and published in the Journal of the Japan Institute of Metals, Committee Report, **3** (1950), 9-Division page 1.

(1) W. Köster, Arch. Eisenhüttenw., **6** (1932), 17; Metal & Alloys, **4** (1933), 69; Metallwirts., **15** (1936), 559.

(2) T. Mishima, Ohm, **19** (1932), 353. (In Japanese)

(3) K. Honda, H. Masumoto and Y. Shirakawa, Sci. Rep. Tohoku Univ., **23** (1934), 365.

(4) K.S. Seljester and B.A. Rogers, Trans. Amer. Soc. Steel Treat., **19** (1932), 553.

the alloys containing 18.5, 21.1 and 27.9 per cent of wolfram and the coercive force of 219 oersteds on the alloy containing 23.4 per cent of molybdenum. However, they explained only the relationship between the magnetic hardness and the role of hardening elements, but not made a systematic study of the magnetic properties of these alloys. The magnetic characteristics of the alloy of iron, wolfram and molybdenum system have not yet been measured, so far as the present writers are aware. Hence, the measurement was systematically carried out on these ternary alloys in the range of concentration of more than 50 per cent of iron and of less than 40 per cent of wolfram and of molybdenum.

II. Specimens and method of measurements

The materials used in preparing the alloys were electrolytic iron of Nippon-Denkai-Seitetusho, and molybdenum- and walfram-powder (compressed lumps) of the Tôhoku Metal Industry Co. A suitable proportion of these metals was weighed, mixed, and then melted under hydrogen atmosphere in an alumina crucible placed in a Tamman furnace. The melt was cast into an iron mould, 6 mm in inner diameter. Finally, it was finished with a grinder into a specimen, 5 mm in diameter and 10 cm in length.

The compositions of 40 specimens used are shown in Table 1, in which the percentages are related to the charged state.

The measurement was carried out by the ballistic method applying the maximum external field up to 1500 oersteds.

III. Heat treatment

To study age hardening alloys at all, it will be necessary first to determine the quenching temperature, the cooling rate and the tempering temperature and time suitable for each alloy. However, the present investigation was obliged to be carried out in the following way:

It was infeasible to determine the quenching temperature suitable for the alloys, in as much as the ternary diagram of iron, walfram and molybdenum system had not fully been decided. However, from the practical point of view, the specimens were heated in molten salt at 1300°C for 20 minutes and quenched in ice water of 0°C, and so the cooling rate was extremely high at 1000°C.

As for the tempering temperature, even if it is moderate, there is no reproducibility of the maximum characteristic when the time is too short. Therefore, the specimen was tempered at temperatures 560～720°C for 3 hours with an interval of 20°C.

IV. Results

The results of measurement, for example, with regard to the alloy containing 75 per cent of iron, 15 per cent of wolfram and 20 per cent of molybdenum are given in Fig. 1. The temper curves in Fig. 1 were obtained by soaking the alloy in molten salt at 1300°C for 20 minutes, quenching it thereafter in water of 0°C

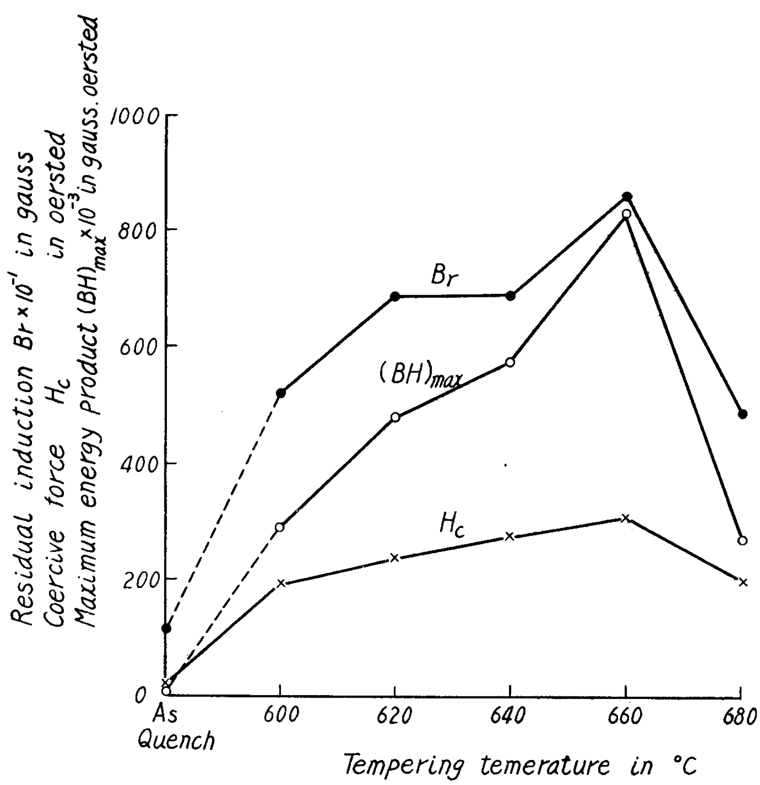

Fig. 1. Effect of the tempering temperature at 3 hrs duration on the magnetic properties of an alloy containing 75 % Fe, 15 % W and 15 % Mo which is quenched from 1300°C into water at 0°C.

and finally heating it at the temperatures ranging from 600 to 680°C for 3 hours. As seen in Fig. 1, the characteristics of the alloy are poor as quenched, but when heated up to 600°C, they begin to show a considerably large value, reaching at 660°C a maximum value of the residual induction Br of 8600 gaussse, the coercive force H_c of 310 oersted and the maximum energy procuct $(BH)_{\max}$ of 835000 gauss oersteds.

The tempering temperatures at which the coercive force becomes largest and the corresponding characteristics obtained from the temper curves for 40 specimens are given in Table 1, in which m in the right column is the dimension ratio, l/d, of each specimen, corresponding to the condition in which the energy product of the specimen was maximum at zero external field. The demagnetizing factors used were obtained by extrapolating Schuddemagen's value.

From Table 1, the contour lines of the residual induction, the coercive force and the maximum energy product on a component concentration diagram are shown respectively in Figs. 2, 3 and 4.

As seen in Fig. 2, the residual induction changes more markedly with the content of molybdenum than that of wolfram, and diminishes as the content of both elements increases. As shown in Fig. 3, the coercive force increases steeply according as the content of wolfram and molybdenum, showing the maximum value of 360 oersteds in the alloy containing 15 per cent of wolfram and 20 per

Table 1. Magnetic Characteristrics of Fe-W-Mo Alloys.

Specimen No.	Composition (%) Fe	W	Mo	Tempening Temperature (°C)	Br (Gauss)	H_c(Oersted)	$(BH)_{max}\times 10^{-3}$ (Gauss Oersted)	m
1	90	10	0	680	8,700	10	65	40
2	70	30	0	660	7,200	116	324	11
3	60	40	0	680	4,500	85	127	10
4	85	10	5	680	10,600	50	285	5
5	75	20	5	640	9,000	135	440	12
6	65	30	5	640	5,600	150	311	9
7	90	0	10	660	11,320	35	244	28
8	85	5	10	660	9,700	93	378	15
9	80	10	10	680	9,500	152	654	11
10	70	20	10	620	8,500	290	875	7
11	65	25	10	660	5,800	135	307	9
12	60	30	10	640	4,800	165	291	7
13	50	40	10	660	5,900	134	277	9
14	85	0	15	640	6,750	200	448	8
15	80	5	15	620	8,400	165	557	9
16	75	10	15	660	7,500	224	724	7
17	70	15	15	660	8,600	310	835	7
18	65	20	15	640	6,600	245	605	7
19	60	25	15	640	5,600	230	364	7
20	55	30	15	640	5,400	250	384	6
21	80	0	20	640	8,500	180	479	8
22	75	5	20	640	4,800	285	435	5
23	70	10	20	620	6,950	335	830	7
24	65	15	20	620	6,400	360	640	5
25	60	20	20	640	7,300	280	600	6
26	50	30	20	640	6,200	250	441	6
27	75	0	25	640	7,400	260	638	7
28	70	5	25	640	4,200	275	332	3
29	65	10	25	620	4,900	260	345	5
30	60	15	25	620	3,100	285	237	4
31	55	20	25	620	4,900	290	397	5
32	70	0	30	620	6,700	425	847	4
33	65	5	30	620	4,000	160	198	7
34	60	10	30	640	2,380	166	128	5
35	50	20	30	620	1,320	184	73	3
36	65	0	35	660	2,580	190	150	4
37	60	5	35	660	2,000	210	121	3
38	55	10	35	640	1,220	185	66	12
39	60	0	40	620	2,000	146	84	5
40	50	10	40	660	670	175	30	2

cent of molybdenum and of 425 oersteds in the alloy containing 30 per cent of molybdenum but not wolfram. The change in the maximum energy product, as seen in Fig. 4, is similar to that of the coercive force and its maximum value is 875×10^3 gauss oersteds in the alloy containing 20 per cent of wolfram and 10 per cent of molybdenum, which shows fairly excellent characteristics of the residual induction of 8500 gausses and of the coercive force of 290 oersteds.

Summarizing the above three graphs, three-component ranges which satisfy the three classified characteristics listed in Table 2 are shown in Fig. 5. As seen in Fig. 5, in the component range limited from about 13 to about 16 per cent of

Table 2. 3 Kinds of Characteristics for Fe-W-Mo Alloys.

Group	Br (Gauss)	H_c (Oersted)	$(B \cdot H)_{max} \cdot 10^{-3}$ (Gauss Oersted)
I	>6,000	>300	>600
II	>8,000	>200	>600
III	>8,000	>300	>800

wolfram, from about 14 to about 17 per cent of molybdenum and from about 69 to about 71 per cent of iron the characteristics are most excellent, that is, the residual induction is more than 8000 gausses, the coercive force more than 300 oersteds and the maximum energy product more than 800000 gauss oersted.

Furthermore, if this alloy is to be actually used as a permanent magnet, it would be necessary to make experiments concerning the temperature coefficient of the residual induction, the aging due to heating and the effect of the mechanical vibration. In the present paper, however, the magnetic characteristics of the alloys of iron, wolfram and molybdenum are solely reported.

In conclusion, the present authors wish to express their cordial thanks to Messrs. Ippei Hoshino, Minoru Aizawa, Jūji Matsuki, Kōtaro Shimizu

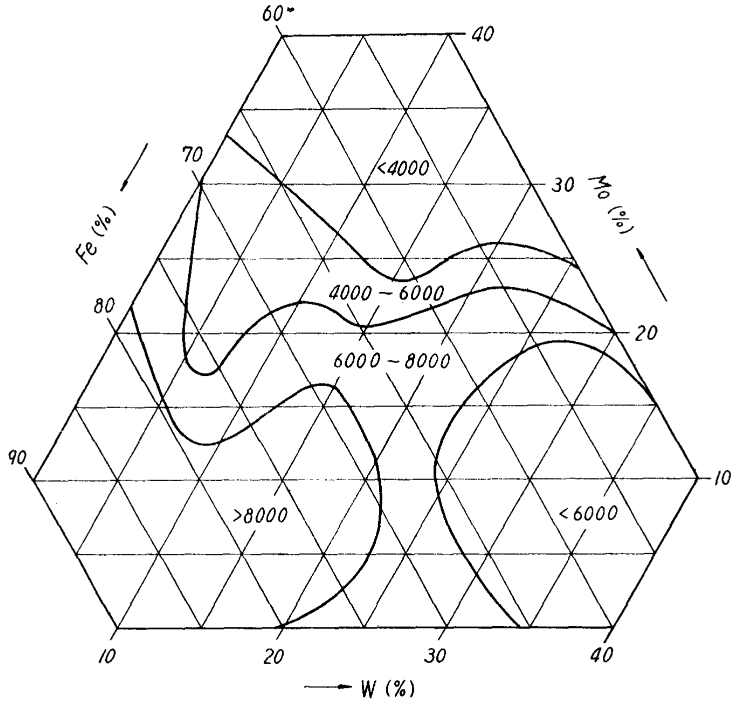

Fig. 2. Residual induction B in gauss of Fe–W–Mo alloys.

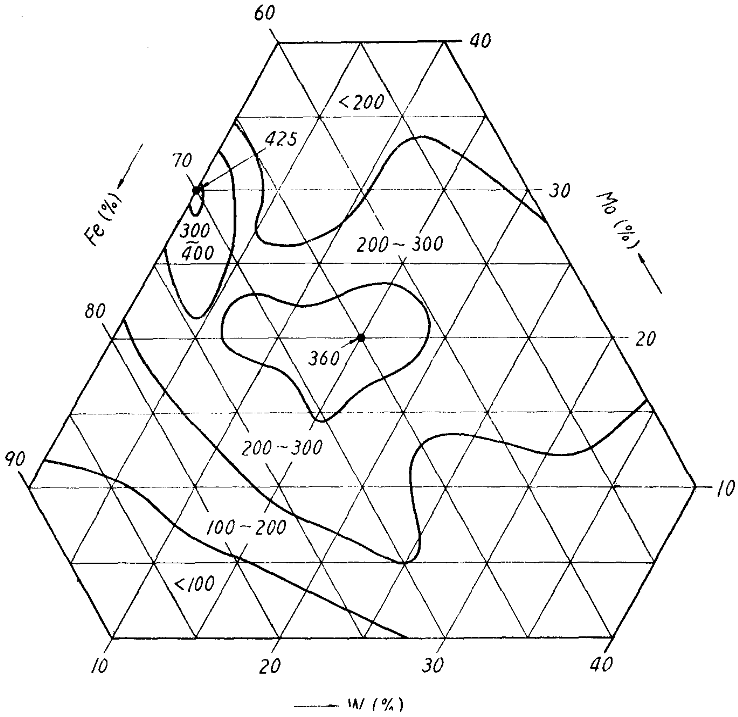

Fig. 3. Coercive force H_c in oersted of Fe–W–Mo alloys.

and Tadashi Satō who were kind enough to participate in this experiments.

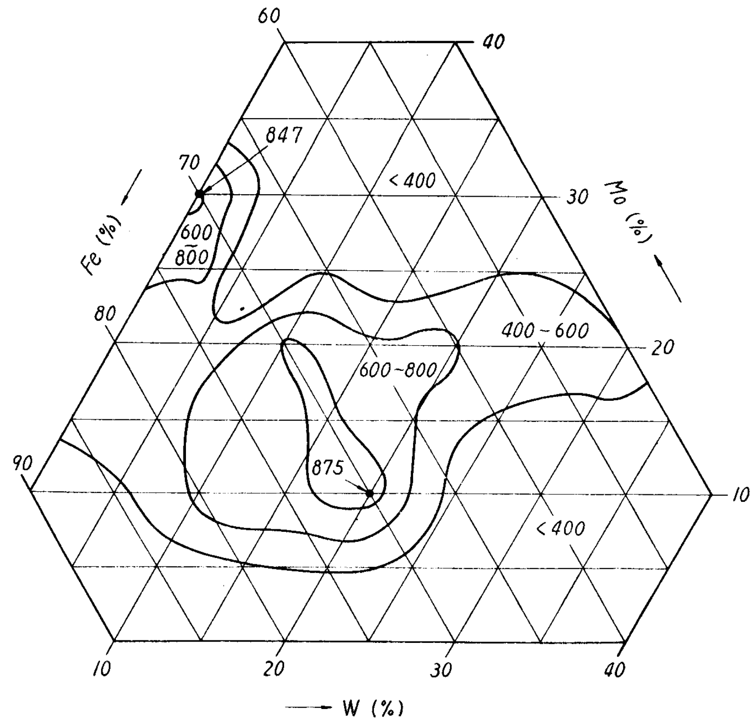

Fig. 4. Maximum energy product $(BH)_{max}$ in 10^3 gauss·oersted of Fe–W–Mo alloys.

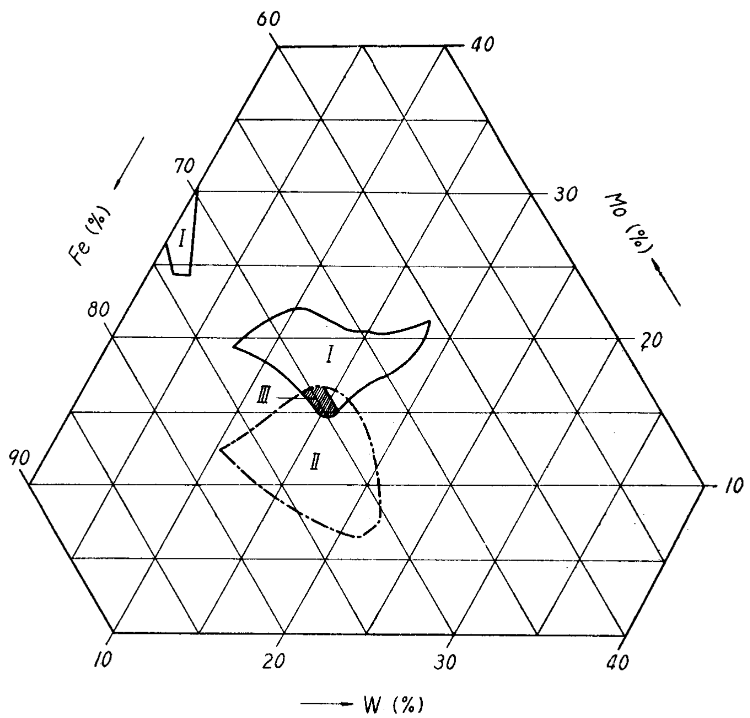

Fig. 5. Regions of composition having some properties for Fe–W–Mo alloys.
Region I : Br>6,000 gausses, H_c>300 oersteds, $(BH)_{max}$>600000 gauss·oersted
Region II : Br>8,000 " , H_c>200 " , $(BH)_{max}$>600000 "
Region III : Br>8,000 " , H_c>300 " , $(BH)_{max}$>800000 "