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ON K. S. MAGNET STEEL.

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SYNOPSIS.

K. S. Magnet Steel.—The composition of this steel is given as C 0.4–0.8 per cent.; Co 30–40 per cent.; W 5–9 per cent.; Cr 1.5–3 per cent. *Tempering* is best effected by heating to 950° C. and quenching in heavy oil. Measurements of the *residual magnetism* for specimens of different composition gave values from 920 to 620 C.G.S. units; the *coercive force* for the same specimens ranged from 226 to 257 gauss. *Artificial aging* by heating in boiling water and by repeated mechanical shock reduced the residual magnetism by only 6 per cent. The *hysteresis curves* for a magnetizing force of ± 1,300 gauss were taken for annealed and tempered specimens; for the annealed specimen the coercive force was 30 gauss and for the hardened steel the coercive force 238 gauss and the energy loss per cycle 909,000 ergs. The *hardness* of annealed and tempered specimens was found to be 444 and 652 respectively on the Brinnell scale and 38 and 55 on the Shore scale. The *microstructure* of the hardened steel showed a finer grain than for the annealed.

ON June, 1917, a new remarkable alloy steel possessing an extremely high coercive force and a strong residual magnetism was discovered by Mr. H. Takagi and one of the present writers (K. Honda). This steel is prominent as a magnet steel among those hitherto known, *i.e.*, tungsten magnet steel, and is named the "K. S. Magnet Steel," after Baron K. Sumitomo, who offered a sum of 21,000 yen to our university for the investigation of alloy steels. During the last two years, several important improvements have been made in the steel, and also numerous measurements of its characteristic constants made; but for reasons connected with the patent, the publication of these data has been suspended up to the present. In the following pages, a short account of the result of our investigation is given.

The alloy is a speical steel containing cobalt tungsten and chromium. A favorable range of the percentages of these metals is given below:

C	Co	W	Cr
0.4–0.8%	30–40%	5–9%	1.5–3%

The alloy being somewhat brittle, great care is required in forging the ingot; but with a good deal of practice, one can forge it into any desired shape. For K. S. magnet steel, the best quenching temperature is 950° C., and the best quenching bath a heavy oil. As shown below, K. S. magnet steel requires almost no heat treatment in order to be used as a permanent magnet in electrical instruments.

The following sets of measurements for K. S. magnet steel are described below:

(*a*) Values of residual magnetism and coercive force.
(*b*) Hardness and microstructure.
(*c*) Hysteresis curves for annealed and quenched steels.
(*d*) Effect of artificial aging,
  (i) Heating in boiling water,
  (ii) Mechanical shock.
(*e*) Effect of the dimension of the specimen on residual magnetism.

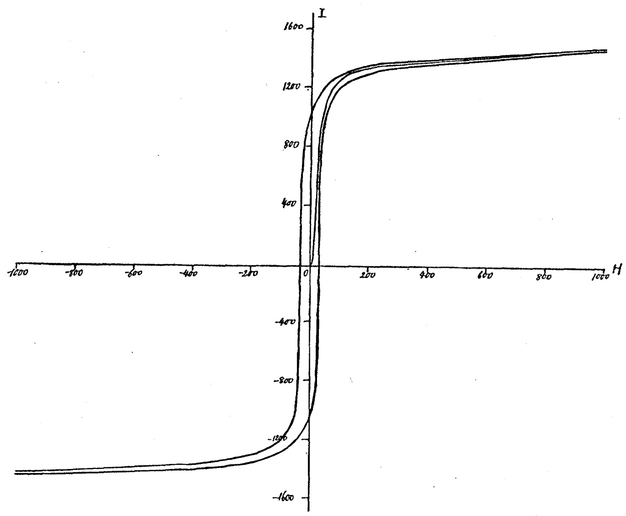

Fig. 3.
Annealed specimen.

The specimens were tested in the form of a cylindrical rod, 20 cm. long and 5 mm. thick. The intensity of magnetization was measured by the ballistic method in the usual way. The magnetizing coil was 40 cm. long and wound in thirteen layers with an insulated copper wire about 1.5 mm. thick, the coil constant being $4\pi n = 483.4$, where n is a number of turns in unit length of the coil. The effective field H was calculated by the well-known relation

$$H = H' - IN,$$

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Plate I.
To face page 496.

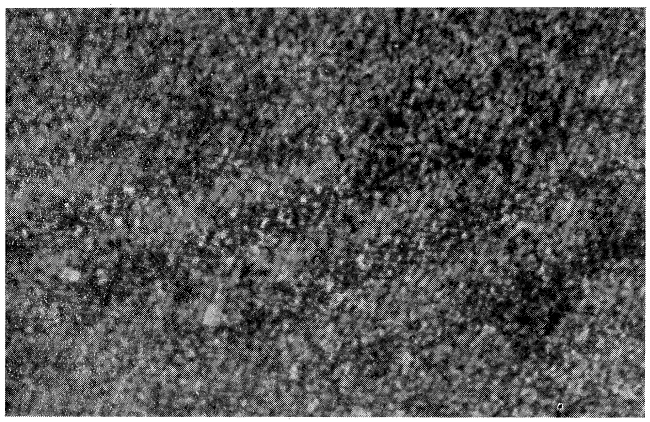

Fig. 1.

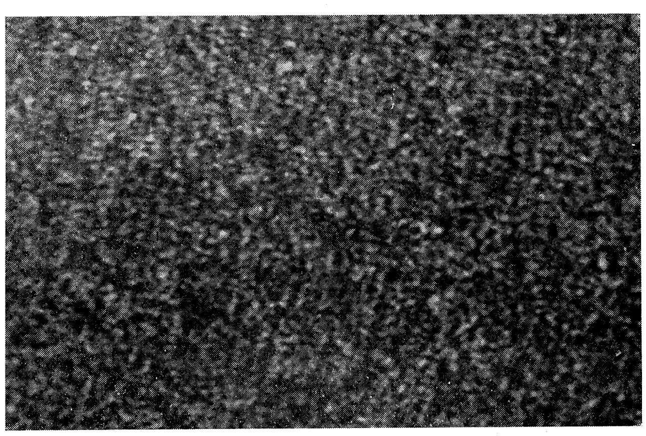

Fig. 2.

K. HONDA AND S. SAITO.

where H' is the applied field, I the intensity of magnetization and N the demagnetizing factor.

Residual Magnetism and Coercive Force.—Two important quantities for a permanent magnet are the intensity of residual magnetism I_r and coercive force H_c, of which the latter is more important than the former. Since these quantities increase with the magnetizing field, a strong field of about 1,500 gausses was applied in our experiment. By varying the percentages of carbon, tungsten, cobalt and chromium within certain limits, alloys having different values of I_r and H_c can be obtained. The following table contains some of the values hitherto obtained:

Specimen.	I_r (C.G.S.).	H_c (ganss).
No. 1	920	226
2	841	221
3	828	245
4	620	257

Thus the coercive force is about three times greater than that of the best tungsten steel hitherto known. The residual magnetism is also greater than that of the tungsten steel.

Hardness and Microstructure.—The hardness of a steel is closely related to its microstructure. Generally speaking, the harder the steel, the finer the structure. The Brinell and the Shore hardness of an annealed and quenched K. S. steel are given in the table below:

	Brinell.	Shore.
Hardness (annealed)	444	38
" (quenched)	652	55

In Figs. 1 and 2, the microphotography of annealed and quenched K. S. steel is given; the microstructure of these specimens consists of an aggregate of very fine grains.

The hardness is also intimately related to magnetism; *i.e.*, mechanically hard steel is also magnetically hard. Thus, since K. S. steel is mechanically very hard and has a very fine structure, it cannot be easily magnetized; but when it is once strongly magnetized, its residual magnetism is very large, and cannot easily be lessened.

Hysteresis Curves.—The following table contains the results of observation for the intensity of magnetization in different fields, both of the annealed and quenched states of the same specimen.

These numbers are also plotted in Figs. 3 and 4, together with the hysteresis loops for the cyclic change of magnetizing field between

Annealed.		Quenched.	
H (Gauss).	I (C.G.S.).	H (Gauss).	I (C.G.S.).
19	281	53	54
30	805	91	107
78	1,227	200	365
247	1,372	295	909
377	1,410	344	998
675	1,450	581	1,171
776	1,465	870	1,266
960	1,479	982	1,293
1,322	1,499	1,281	1,346

+ 1300 and − 1300. In the annealed state, the coercive force is only 30 gausses; but in the quenched state, it amounts to 238 gausses and the area of the loop is enormously large, the loss being about 909,000 ergs. In the best tungsten steel, the same quantity is found to be 290,000 ergs.

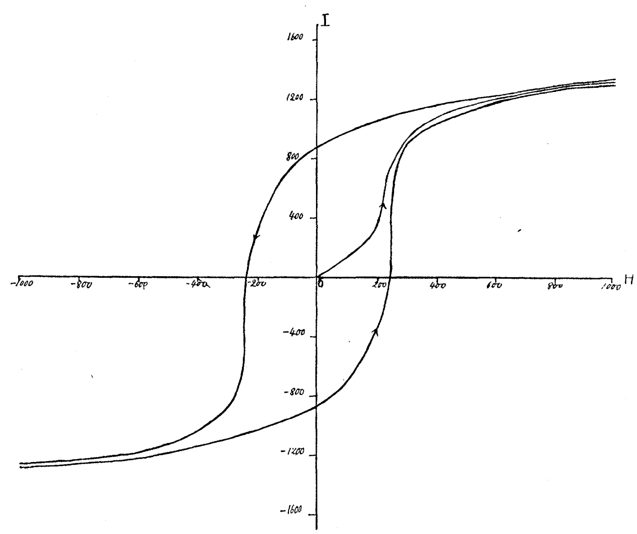

Fig. 4.
Quenched specimen.

Effect of Artificial Aging.—A permanent magnet is always acted on by a demagnetizing force due to the end distribution of magnetism; this force rapidly increases, as the dimension ratio of the specimen decreases. The heating process of the specimen is to expose it to molecular vibrations under the action of the demagnetizing force, and hence residual magnetism is usually reduced by a considerable amount during a prolonged heating, especially in a short specimen, for which the demagnetizing force is large. Since K. S. steel has a large coercive force, it may be expected strongly to resist the weakening effect of prolonged heating.

The effect of heating the specimen in boiling water is graphically given in Fig. 5, *a*. A rod of K. S. steel having the same dimensions as before was quenched, and strongly magnetized in a coil. The specimen was afterward constantly heated in boiling water, and its residual magnetism measured from time to time for 40 hours. From the curve, we notice that during the first heating for three hours, the residual magnetism slightly increases and afterwards remains perfectly constant. In other K. S. magnet steels, it is usual to observe a slight decrease of magnetization for the first one or two hours of heating, and then an increase to its former value at about three hours, the magnetization afterwards remaining constant (curve *b*). This decrease and increase of magnetization are due to the simultaneous action of two opposite causes. The first decreasing cause is the molecular vibration due to heating, and the second increasing cause the tempering; that is, during heating, a small fraction of carbides, which are present as a solid solution, is set free, and hence the magnetism increases. The effects of these two causes soon reach their asymptotic values as the heating continues. Hence the superposition of these two effects results in the decay curve (*b*), as actually observed. When the first effect is very small, the curve takes the form as shown in curve (*a*).

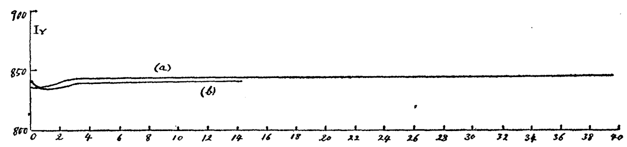

Fig. 5.
Decay curve in boiling water.

The effect of a repeated shock was also observed; a specimen of the same dimensions as before was quenched and magnetized by a strong field; it had initially a residual magnetism of 854 C.G.S. units. Two series of experiments were made; in one, the specimen was repeatedly allowed to fall on a wooden floor from a height of one meter, and in the other, on a concrete floor from the same height. The result of experiments is graphically given in two curves in Fig. 6. The ordinate is the residual magnetism and the abscissa the number of falls. The first diminution of magnetization is comparatively rapid up to 20 falls, and afterwards very slow. The fall on the concrete floor has a greater demagnetizing effect by about 6 C.G.S. units than the fall on the wooden floor. After 850 repeated falls on the concrete floor, the intensity of residual magnetism diminished from 854 to 800 C.G.S. units.

Effect of Dimensions on Residual Magnetism.—As the dimension ratio of a permanent magnet decreases, the demagnetizing force acting in the

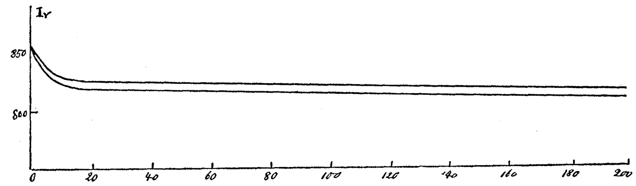

Fig. 6.

I_r—fall number curve.

interior of the magnet becomes greater, and hence the residual magnetism rapidly decreases with the dimension ratio. The resistance to this demagnetizing action is measured by the coercive force. Suppose the length of a bar magnet be gradually diminished, then the material having a smaller coercive force undergoes a greater diminution of magnetism than one having a greater coercive force. Hence, for a bar magnet, K. S. magnet steel has a very great advantage over the ordinary tungsten steels. For a dimension ratio of 15, the permanent magnetism of K. S. magnet steel is about 1.8 times stronger than that of the tungsten steel.

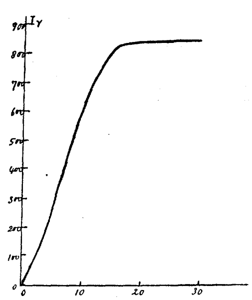

Fig. 7.

I_r—dimension ratio curve.

In Fig. 7, the I_r-dimension ratio curve for K. S. magnet steel is given. It shows how rapidly the residual magnetism increases with the increasing ratio of the dimensions, and that above the ratio of 20, the residual magnetism is not affected by the ratio.

Summary.

1. K. S. magnet steel has an extremely large coercive force; its intensity of residual magnetism is also considerably larger than that of ordinary tungsten steels.

2. The area of the hysteresis loop of K. S. magnet steel is very large.

3. K. S. magnet steel, when quenched, is mechanically very hard, and has a very fine microstructure.

4. The residual magnetism of K. S. magnet steel does not appreciably diminish by a prolonged heating at 100° C. over many hours.

5. 850 repeated falls of the steel bar from a height of one meter on a concrete floor causes only a diminution of magnetization by 6 per cent. of its initial value.

6. K. S. magnet steel is specially suited for short bar magnets.

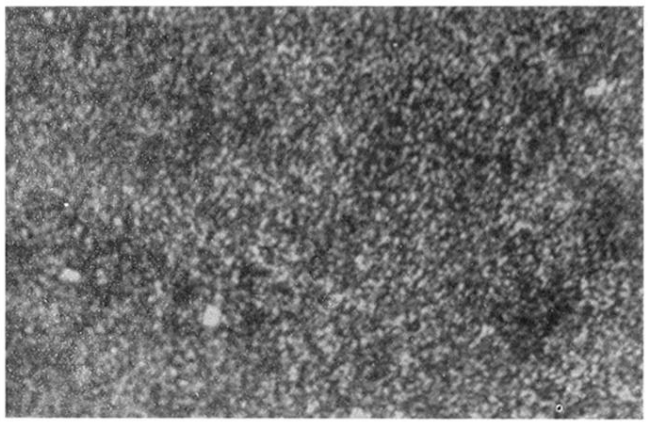

Fig. 1.

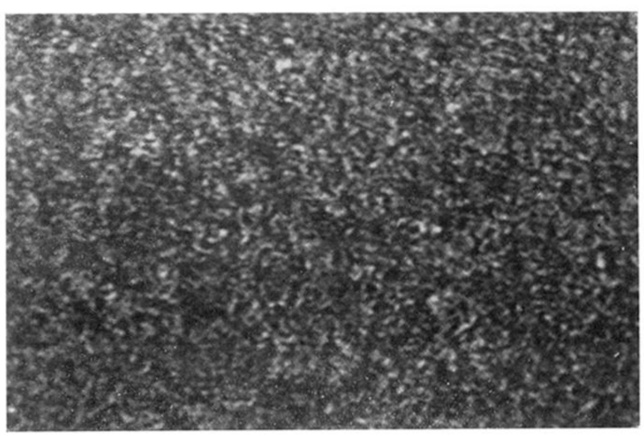

Fig. 2.