THE PROPERTIES OF HIGH-SPEED STEEL DERIVED FROM MAGNETIC IRON SAND

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Introduction

THE characteristic properties of steel are influenced by its derivation, namely the type of raw iron used and the method of manufacture, as well as the working treatment which includes the hot and cold-working and heat treatment. Of these factors the quality of raw iron and the choice of the manufacturing method have an especially important effect on the characteristics of the steel produced. The Yasugi Works of Hitachi Ltd. has been engaged for several decades in the study and manufacture of high-speed steel and high quality special steels of various types, using as the basis of its work the high grade magnetic iron sand produced in the Izumo-Hoki area.

It is the aim of the lecturer to state the properties for raw iron derived from magnetic iron sand as well as the properties of high-speed steels derived therefrom, with special reference to their superiority.

Properties for Raw Iron Derived from Magnetic Iron Sand

The magnetic iron sand ores obtained in the western part of Japan proper, especially the San-in area of it, are of very high quality.

An analysis of the composition of a few representative types of magnetic iron sand produced in this area, together with iron sand ores obtained in other areas, is shown in Table 1.

As can be seen from Table 1, magnetic iron sand produced in the San-in area has a low phosphorus content and an extremely low percentage of TiO_2. Generally speaking, iron sand ore often contains chromium and vanadium in addition to titanium as useful elements, but the magnetic iron sand mined in the San-in area contains practically no chromium. The vanadium content varies slightly according to location. As a measure of quality, a high iron content is naturally desirable, but at the same time it is extremely important, not only for the refining process but for the final quality as well, that the proportion of phosphorus, sulphur, copper and TiO_2 be as low as possible.

'Tamahagane', or the traditional Japanese wrought steel, is produced by the ancient Tatara method of iron manufacture. In this method magnetic iron sand is placed in a Tatara furnace with a large quantity of charcoal and reduced at a relatively low temperature in a blast of cold air to produce steel directly. 'Tamahagane' is used as raw material of 'Japanese Sword'.

Although 'Tamahagane' can be produced by the direct method as described above, the economic drawbacks of this system have led us to use another method of production in which iron sand and charcoal, together with a small quantity of lime, are placed in an electric arc furnace, melted at a high temperature, and the melt is thrown into a water tank to produce refined shot steel (shown in FIG. 1), or poured into ingot cases to form what is called a sand mass. The refined shot steel produced by the above method of iron sand refining is a raw iron material of high purity, having an extremely low gas content, a very low percentage of silicon,

TABLE 1 — CHEMICAL COMPOSITION OF MAGNETIC IRON SAND PRODUCED IN THE SAN-IN AREA AND OTHER IRON SAND ORES IN OTHER AREAS

Producing locality	Total Fe	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	MnO	P	S	Cu	TiO_2	Ignition loss	TiO_2 content per 100 parts of Fe
Nitta-gun, Shimane Pref.	63·01	22·89	64·75	9·14	0·34	1·18	0·69	0·96	0·010	0·034	0·035	1·47	0·90	2·33
Nitta-gun, Shimane Pref.	67·10	28·14	64·67	3·28	0·50	1·18	0·87	0·91	0·016	0·046	0·046	2·61	0·74	3·81
Nitta-gun, Shimane Pref. (Torikami-mura)	67·46	32·97	59·81	3·74	0·42	1·23	1·93	0·64	0·005	0·033	0·058	1·63	0·68	2·42
Nitta-gun, Shimane Pref. Fukuyori	61·40	21·40	63·30	5·20	2·54	1·76	0·60	—	—	—	—	1·88	—	—
Nitta-gun, Shimane Pref. Toge-no-tani	61·42	24·84	60.00	6·20	1·80	2·68	0·49	—	—	—	—	2·12	—	—
Nitta-gun, Shimane Pref.	61·45	30·41	54·01	6·64	0·35	2·45	1·33	1·55	0·040	0·061	0·081	5·05	0·80	8·22
Nitta-gun, Shimane Pref. Ku-mura	45·44	24·27	37·90	8·53	6·28	3·45	2·56	0·01	0·139	—	—	9·25	—	—
Kumage-gun Kagoshima Pref.	54·22	36·59	36·88	4·50	3·96	1·78	4·12	1·49	0·191	0·092	0·120	10·78	0·33	19·88
Atetsu-gun, Okayama Pref.	55·10	25·94	45·95	4·84	2·75	0·80	1·28	1·48	0·057	0·072	0·168	11·78	1·76	21·38
Kariwa-gun, Niigata Pref.	55·10	27·76	47·94	4·07	4·26	0·97	3·14	0·42	0·070	0·028	0·026	12·99	0·35	23·39
Hiba-gun, Hiroshima Pref.	60·42	22·56	61·31	5·42	1·60	1·59	1·56	1·01	0·169	0·159	0·059	5·79	1·03	9·58
Kuji, Kube-gun, Iwate Pref.	54·20	30·87	43·18	6·38	1·88	1·26	6·85	0·42	0·040	0·025	0·057	12·58	0·67	23·21
Shimokita-gun, Aomori Pref.	57·07	31·24	46·88	3·60	4·16	—	2·06	0·91	0·071	0·008	0·069	16·54	0·55	28·98

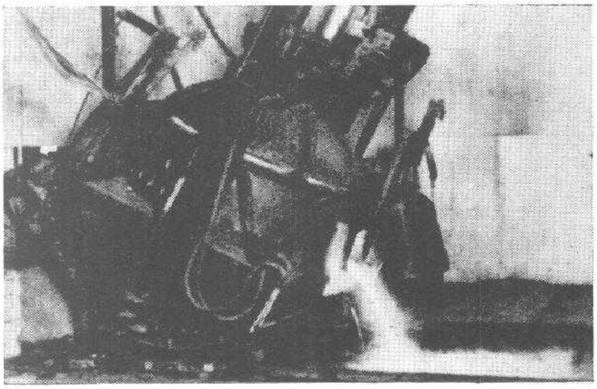

FIG. 1 — APPEARANCE OF MANUFACTURE OF SHOT STEEL

manganese, phosphorus and sulphur, and being practically free from traces of nickel, chromium and copper. A few examples of the analysis of this type of refined shot steel and sand mass are shown in Table 2.

Another method of reduction, in which magnetic iron sand is alternately arranged with charcoal in a small blast furnace called ' Kaku-ro ', and refined by deoxidization at a relatively low temperature in a warm blast introduced from the tuyere, yields a white pig iron of extremely high quality known as charcoal pig iron. Fig. 2 shows the outward appearance of ' Kaku-ro '. Examples of analysis are given in Table 2. This white pig iron is also used for the production of high quality special steels by the Company. Fig. 3 shows these raw iron materials.

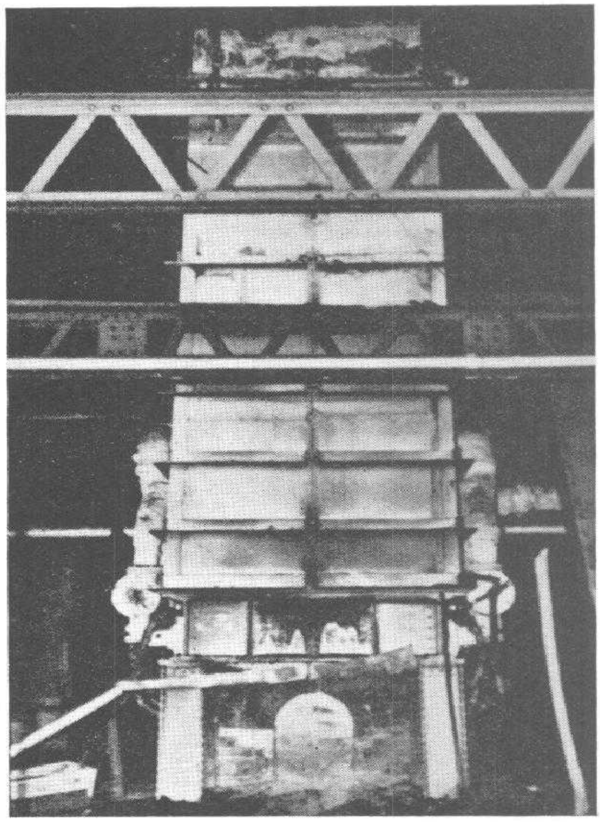

FIG. 2 — OUTWARD APPEARANCE OF ' KAKU-RO '

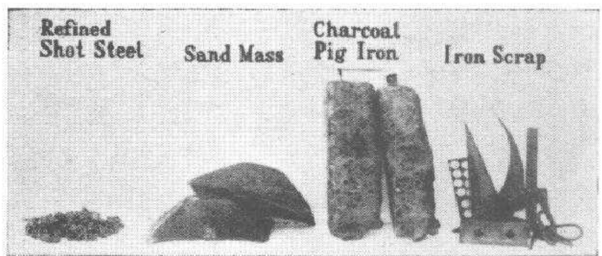

FIG. 3 — RAW IRON MATERIALS

TABLE 2 — CHEMICAL COMPOSITION OF REFINED SHOT STEEL AND OTHERS

	C	Si	Mn	P	S	Ni	Cr	Cu
Refined shot steel	0·05	0·05	0·10	0·010	0·005	Nil	0·05	Tr
Refined shot steel	0·07	Tr	0·10	0·011	0·005	Nil	0·02	Tr
Sand mass	0·04	0·07	0·05	0·012	0·010	Nil	0·03	Tr
Charcoal pig	3·52	0·04	0·08	0·073	0·008	Nil	0·02	Tr
Charcoal pig	3·40	0·25	0·10	0·050	0·005	Nil	0·05	Tr
' Tamahagane '	1·33	0·03	0·04	0·014	0·006	Tr	0·05	Tr

High-speed Steel Produced from Iron of Iron Sand Origin

High-speed steel is the most widely used type of steel for cutting tools. The Yasugi Works of Hitachi Ltd. has been engaged in the manufacture of high-speed steel from raw iron of iron sand origin since its establishment and has been carrying on experimental research over a wide field for more than a decade, especially in regard to a detailed study of chemical composition and heat treatment methods.

Effect of Chemical Composition — The cutting durability of high-speed steel is greatly affected by the nature of raw material, processes of manufacture, methods of heat treatment, etc., but no less great is the effect of the chemical composition of steel on cutting durability. In a desire to save the consumption of the metallic components and yet to obtain better grades of high-speed steel, we have made a peculiar investigation on the chemical composition of high-speed steel produced in the past.

In this test raw iron made from magnetic iron sand, a product peculiar to our Company, was used. The standard composite elements accepted in the test were: C, 0·8; Cr, 4; W, 20; Mo, 1; and V, 2 per cent. An effort was made to seek the effect of each of these elements by changing its content. At the same time, an experiment was conducted as to similar steel containing 5-25 per cent Co.

First the effect of the elements on quenching and tempering hardness was determined and the characteristic curve of tempering sought. Along with this, a microstructural study was made in order to find out proper heat treatment methods for different kinds of high-speed steel. In an actual lathing test the effect of the chemical composition of steel on cutting durability was examined. The material chosen for cutting was nickel-chromium steel quenched and tempered, the Brinell hardness of which ranged from 350 to 360; a comparative study of cutting durability was made at a 20-minute durable cutting speed. Figs. 4-9 show the effects of the various elements on cutting durability.

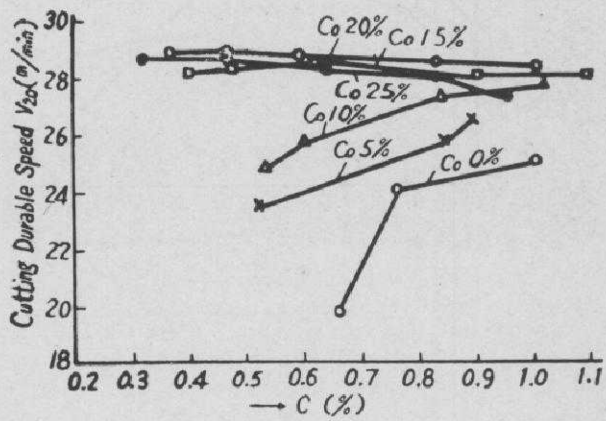

FIG. 4 — RELATION BETWEEN CARBON CONTENT OF HIGH-SPEED STEEL CONTAINING VARIOUS COBALT AND CUTTING DURABILITY (Cr, 4; W, 20; V, 2; Mo, 1 PER CENT)

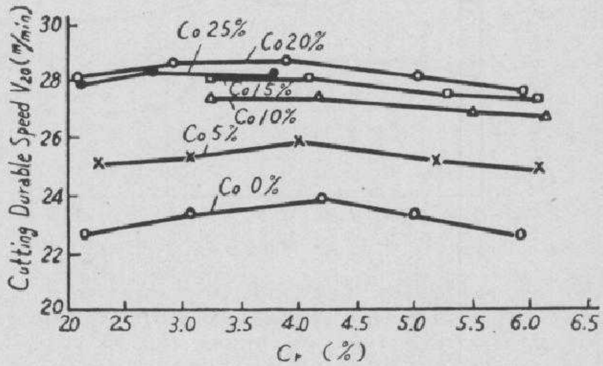

FIG. 5 — RELATION BETWEEN CHROME CONTENT OF HIGH-SPEED STEEL CONTAINING VARIOUS COBALT AND CUTTING DURABILITY (Co, 8; W, 20; V, 2; Mo, 1 PER CENT)

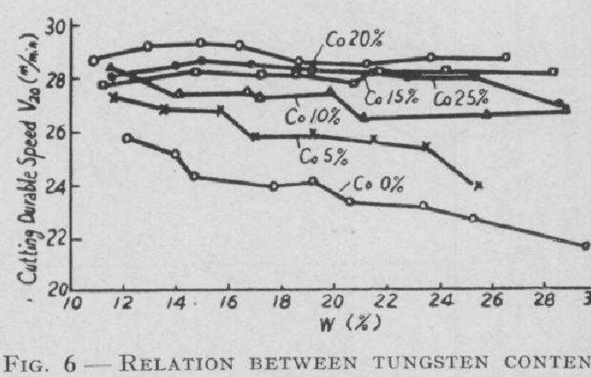

FIG. 6 — RELATION BETWEEN TUNGSTEN CONTENT OF HIGH-SPEED STEEL CONTAINING VARIOUS COBALT AND CUTTING DURABILITY (Co, 8; Cr, 4; V, 2; Mo, 1 PER CENT)

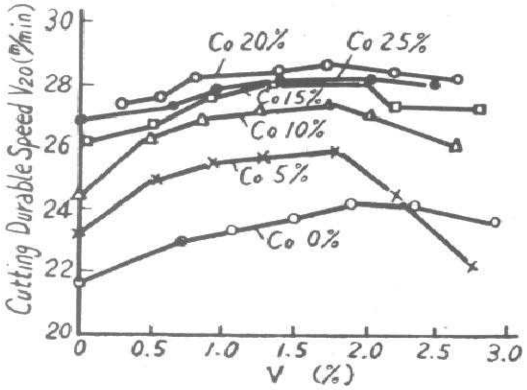

FIG. 7 — RELATION BETWEEN VANADIUM CONTENT OF HIGH-SPEED STEEL CONTAINING VARIOUS COBALT AND CUTTING DURABILITY (Co, 8; Cr, 4; W, 20; Mo, 1 PER CENT)

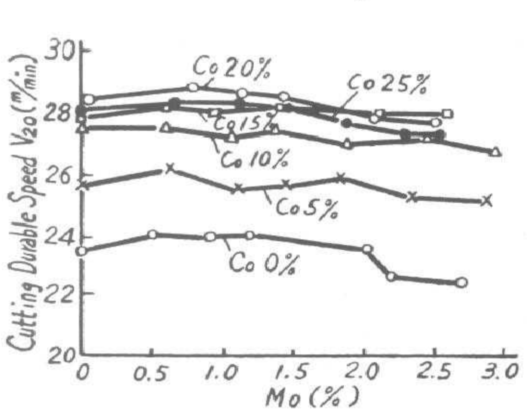

FIG. 8 — RELATION BETWEEN MOLYBDENUM CONTENT OF HIGH-SPEED STEEL CONTAINING VARIOUS COBALT AND CUTTING DURABILITY (Co, 8; Cr, 4; W, 20; V, 2 PER CENT)

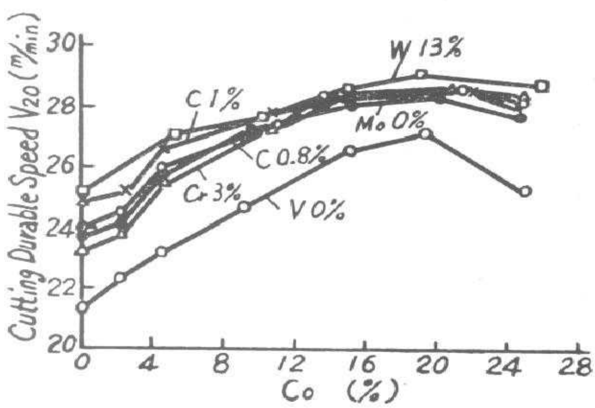

FIG. 9 — RELATION BETWEEN COBALT CONTENT OF VARIOUS HIGH-SPEED STEEL AND CUTTING DURABILITY (STANDARD COMPOSITION: Co, 8; Cr, 4; W, 20; V, 2; Mo, 1 PER CENT)

In case of steel containing up to 10 per cent of cobalt, the durability attains its maximum value at carbon content of 1 per cent. When the cobalt content exceeded 15 per cent, the carbon content indicating the highest durability tended to sag, especially when the said content was higher than 20 per cent, durability was highest provided the carbon content was 0·2 to 0·4 per cent.

In the case of chromium containing different amounts of Co, durability reached its maximum generally at around 4 per cent. The durability of tungsten was highest in the neighbourhood of 11-12 per cent, when the cobalt content was up to about 10 per cent; but when the cobalt content exceeded 15 per cent, there was observed a gradual tendency towards high tungsten. Especially conspicuous was the effect of low tungsten of 12 per cent or so, when the cobalt content was small. Vanadium showed its highest durability at 1·5-2·0 per cent, when the cobalt content was up to 20 per cent; but when more than 20 per cent cobalt was contained, durability was highest in the neighbourhood of 1·5 per cent. Molybdenum produced almost no effect on cutting durability up to about 1·5 per cent. So far as the high-speed steel tested in this experiment was concerned, the highest durability of cobalt was obtained at 17-20 per cent.

By the results of the aforementioned basic research it was ascertained that low-tungsten high-speed steel of 10-12 per cent W is superior to high-tungsten high-speed steel as produced in the past. After examining the effects of elements like C, Cr, V, Mo and Co, the best composition of low-tungsten high-speed steel of this sort was determined. From the results of these investigations, we could produce a new kind of high-speed steel superior to that of the conventional high-tungsten high-speed steels. And then this low-tungsten high-speed steel has been put in practice as Japanese industrial standard now.

In order, moreover, to determine the effects of Ni, Mn, Si, Al, Sn, Cu, Sb, Ti, B and Zr for low-tungsten high-speed steel, we carried out a series of experiments. Thus, it was established that whereas the effects of small amounts of Ni, Mn and Cu were quite negligible, Si, Al, Sn and Sb proved exceedingly harmful. It was also believed that the addition of very small amounts of Ti, B and Zr ranging from 0·1 to 0·2 per cent was desirable as serving to increase the durability of steel of this kind.

Effect of Heat Treatment on Hardness and Cutting Durability — First it was made clear that there existed an exceedingly close relation between the quenching temperature and the keeping time of quenching. The relation between quenching temperature, keeping time of quenching and cutting durability of the low-tungsten high-speed steel is shown in Fig. 10. As the quenching temperature was raised, the keeping time of quenching indicating maximum hardness and durability was proportionately reduced.

Then, changes in the hardness of quenched high-speed steel resulting from tempering were sought. Further, the effect of single and repeat tempering was ascertained.

A proper tempering temperature became higher as more cobalt was contained and as the quenching temperature was raised. Fig. 11 shows the effects of the quenching and tempering temperatures upon the cutting of low W-Co high-speed steel. In Fig. 12 is shown the effect of repeat tempering upon the

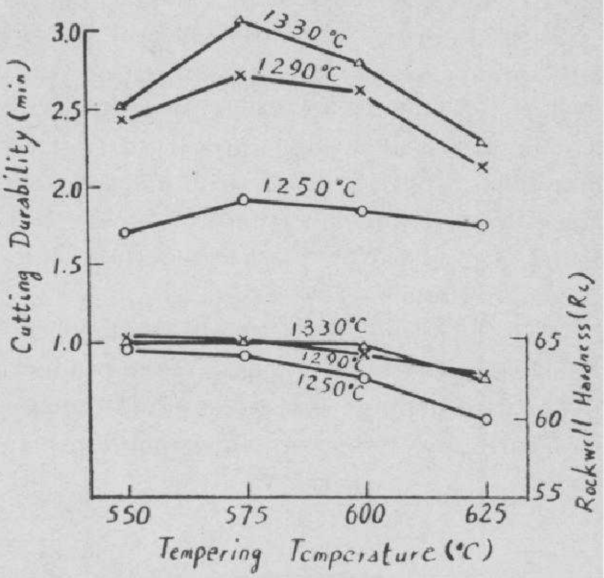

FIG. 11 — RELATION BETWEEN QUENCHING, TEMPERING TEMPERATURE, HARDNESS AND CUTTING DURABILITY OF X00 STEEL (C, 0·75; Cr, 4·45; W, 11·87; V, 1·52; Co, 4·52 PER CENT) (TEMPERING, TWICE)

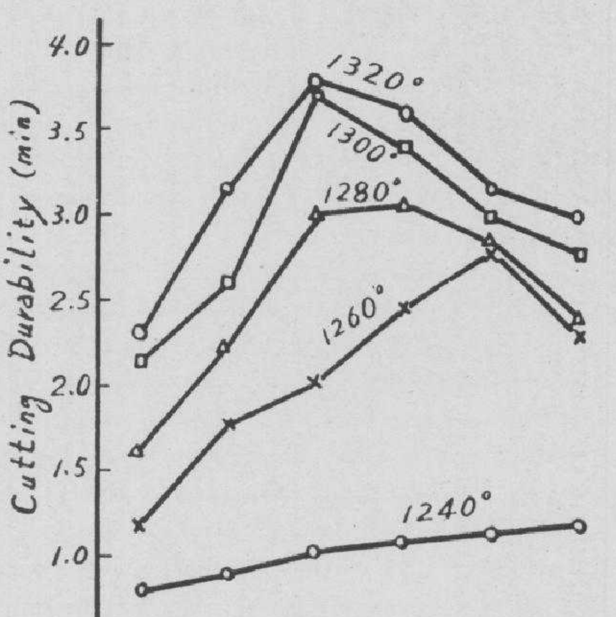

FIG. 10 — RELATION BETWEEN QUENCHING TEMPERATURE, KEEPING TIME AND CUTTING DURABILITY OF X1 STEEL (TEMPERING TEMPERATURE, 570°C.)

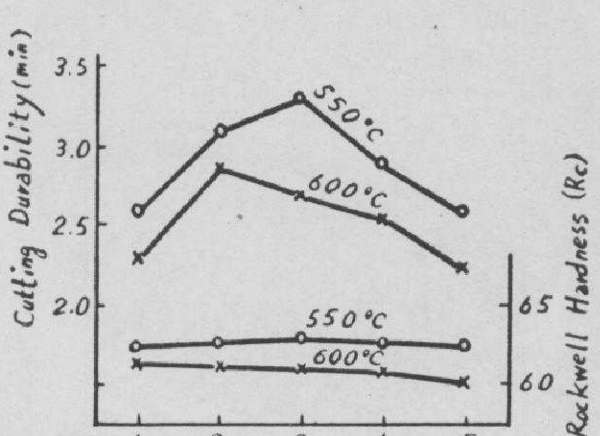

FIG. 12 — RELATION BETWEEN REPEAT TEMPERING, HARDNESS AND CUTTING DURABILITY OF X1 STEEL (C, 0·72; Cr, 4·04; W, 11·41; V, 1·6 PER CENT) (QUENCHING TEMPERATURE, 1300°C.)

cutting durability of low-tungsten high-speed steel. The durability of steel was remarkably increased when tempering was repeated two to three times. The larger the cobalt content was and the higher the quenching temperature was, the more pronounced became the effect of repeat tempering.

The chemical composition of the kinds of high-speed steel made at Yasugi Works of Hitachi Ltd. is shown in Table 3.

Of these types, X1 and X00 steel possess far superior properties in comparison with 18-4-1 steel and 18-4-1-5 steel used hitherto. A comparison of drilling capacity between a first-class foreign* made drill and another made from Hitachi Yasugi X1 steel, on a 5 mm. straight drill, has yielded the results shown in Table 4.

It is clear from these results that Yasugi X1 is superior to the foreign* made product.

The quenching and tempering microstructures of X1 steel are shown in Figs. 13 and 14.

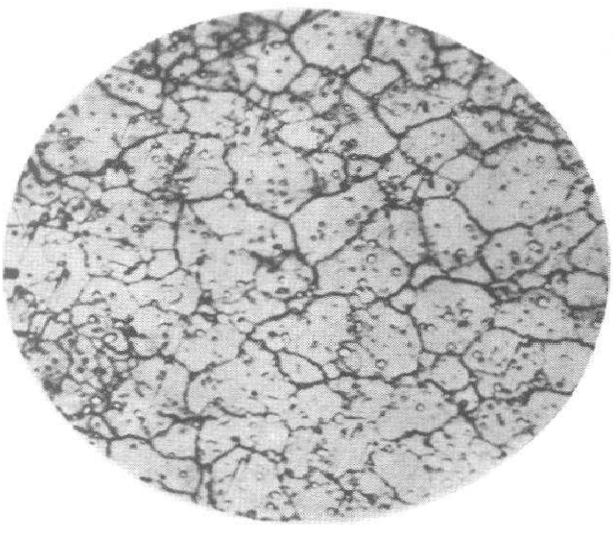

FIG. 13 — QUENCHED MICROSTRUCTURE FROM 1280°C. FOR X1 STEEL. × 400

*Europe and U.S.A.

TABLE 3 — THE CHEMICAL COMPOSITION AND HEAT TREATMENT OF HIGH-SPEED STEEL MADE AT YASUGI WORKS OF HITACHI LTD.

KINDS OF STEEL	CHEMICAL COMPOSITION, PER CENT										ANNEALING TEMPERATURE, °C.	QUENCHING TEMPERATURE, °C.	TEMPERING TEMPERATURE, °C.	HARDNESS AFTER QUENCHING AND TEMPERING (Rc)
	C	Si	Mn	P	S	Cr	W	Mo	V	Co				
X1	0·70~0·80	0·15~0·35	0·25~0·45	<0·025	<0·010	3·80~4·50	10·00~12·00	—	1·60~2·00	—	860~880	1240~1290 oil	570~580 air	>62
X00	0·75~0·85	0·15~0·35	0·25~0·45	<0·025	<0·010	3·80~4·50	11·00~13·00	—	1·60~2·00	4·50~5·50	870~900	1250~1300 oil	570~580 air	>63
X000	0·75~0·85	0·15~0·35	0·25~0·45	<0·025	<0·010	3·80~4·50	14·00~16·00	—	1·60~2·00	9·00~11·00	880~900	1270~1320 oil	580~590 air	>64
HX2	0·70~0·85	0·15~0·35	0·25~0·45	<0·030	<0·010	3·50~4·50	17·00~19·00	—	0·80~1·20	—	860~880	1260~1300 oil	560~580 air	>62
HX3	0·70~0·85	0·15~0·35	0·25~0·45	<0·030	<0·010	3·50~4·50	17·00~19·00	—	0·80~1·20	4·50~5·50	870~900	1270~1310 oil	570~590 air	>63
HX4	0·70~0·85	0·15~0·35	0·25~0·45	<0·030	<0·010	3·50~4·50	17·00~19·00	—	1·00~1·50	9·00~11·00	880~900	1280~1330 oil	570~590 air	>64
XM1	0·75~0·85	0·15~0·35	0·25~0·45	<0·030	<0·010	3·80~4·50	6·00~7·00	4·00~5·50	1·70~2·20	—	870~890	1230~1280 oil	560~580 air	>63

TABLE 4 — COMPARISON OF A 5 mm. STRAIGHT DRILL MADE FROM YASUGI X1 AND A FOREIGN PRODUCT

Cutting speed ... 1920 *r.p.m.*
Cutting load ... 25·5 *kg.*
Cutting oil ... *Mobile*
Testing method ... *Depth of holes to be drilled* — 15 *mm.*

*Test results in cutting T.S.*2 (*C*, 1·05% ; *Cr*, 0·75% ; *W*, 1·30%) (*Rc* 25)

KIND	SAMPLE	TIME REQUIRED FOR DRILLING 1 HOLE	NUMBER OF HOLES DRILLED	REMARKS
Yasugi high-speed steel X1	No. 3	10 sec.	36	Drill shoulder partly worn.
Yasugi high-speed steel X1	No. 4	12~12·5 sec.	60	No appreciable wear observed.
Foreign product (18-4-1)	No. 3	17 sec.	27	Edges at drill tip worn.
Foreign product (18-4-1)	No. 4	15~26 sec.	29	Edges at drill tip worn.

NOTE — From these results, the durability of the foreign product is inferior to the Yasugi product.

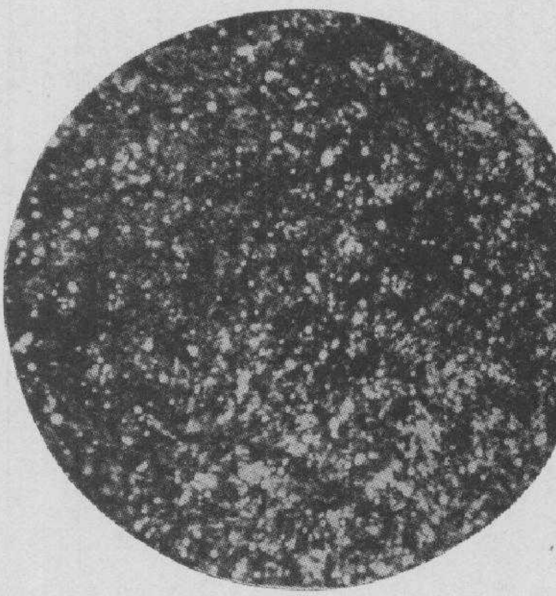

FIG. 14 — TEMPERED MICROSTRUCTURE AT 570°C. AFTER QUENCHING FROM 1280°C. FOR X1 STEEL. × 400

Other High Grade Special Steels

In addition to the high-speed steel described above, die steel being used for wire drawing die and punching dies, and hot-working die steel for extrusion tools are also made from raw iron of magnetic iron sand origin in order to give them greater durability and strength. The type and chemical composition of die steel made at the Yasugi Works of Hitachi Ltd. are listed in Table 5.

Conclusion

The above has been a short description of the high-speed steel products that are being made from the high grade magnetic iron sand ores produced in the San-in area, the western coastal region of Japan proper. Hitherto it has been acknowledged that Swedish steel is the best steel in the world, and the reason for this superiority is ascribed to the high quality of the iron ore produced in that country. The Yasugi Works of Hitachi Ltd. has been engaged in the production of high quality special steel since its establishment on the basis of its many years of experience in steel manufacture from high grade magnetic iron sand, and the superior quality of its products has been generally recognized. It is our intention to continue in our research efforts in the hope of attaining a still higher technical level.

TABLE 5 — THE TYPES AND CHEMICAL COMPOSITION OF DIE STEEL MADE AT YASUGI WORKS OF HITACHI LTD.

Kinds of steel	Chemical composition, per cent									Uses
	C	Si	Mn	P	S	Cr	W	Mo	V	
CRD	2·00	0·25	0·35	<0·025	<0·010	13·50	—	—	—	Drawing dies, punching dies
WRD	2·00	0·25	0·35	<0·025	<0·010	13·50	3·00	—	—	Drawing dies, punching dies
SLD	1·50	0·25	0·35	<0·025	<0·010	12·00	—	0·65	0·35	Punching dies, gauge
SAD	1·05	0·25	0·70	<0·030	<0·010	0·75	1·30	—	—	Punching dies
SBD	1·25	0·25	1·10	<0·030	<0·010	1·15	1·45	—	—	Punching dies
SCD	1·00	0·25	0·50	<0·030	<0·010	5·25	—	1·00	0·35	Punching dies, gauge
WD	2·20	0·25	0·45	<0·030	<0·010	2·75	11·00	—	—	Drawing dies for hard wire
DC	0·30	<0·30	0·40	<0·030	<0·010	2·50	5·50	—	0·40	Hot-working dies
HDC	0·30	<0·25	0·40	<0·030	<0·010	2·50	9·50	—	0·40	Hot-working dies
DAC	0·38	1·00	0·40	<0·030	<0·010	5·20	—	1·40	0·90	Die-casting dies
DBC	0·38	1·00	0·40	<0·030	<0·010	5·20	1·30	1·40	0·35	Die-casting dies