

PROGRESS OF SPECIAL STEEL-MAKING PROCESS IN JAPAN

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Abstract

Special Steel-making in Japan

In Japan special steel-making was started in 1882 by means of the crucible furnace melting, and since 1914 the electric arc furnace steel-making has been studied. The production of arc-furnace steel increased year by year, and subsequently in 1938 crucible-furnace steel was wholly replaced by electric furnace steel.

In 1931 steel-making by means of induction furnace was started.

At first the capacity of the arc furnace was as small as not over 3 tons. However, towards 1932 it was developed to 5-10 tons, and a few 15 and 30 ton furnaces were erected. About 1937 many furnaces rated 10-15 tons were erected. Accordingly the production reached to the maximum amount of 2,258,000 tons, of which the electric-furnace steel occupied 75 per cent in 1944.

After the war the production suddenly decreased to only 80,000 tons, but during the Korean war it increased to 300,000 tons.

In 1954, Japan had 142 arc furnaces, whose total capacity was 1,100,000 tons, and 75 induction furnaces, whose capacity was 140,000 tons.

Owing to the investigation of the Research Institute for Iron, Steel and Other Metals and the 19th Sub-Committee of the Japan Society for the Promotion of Science, the practice of special steel-making of Japan was remarkably improved and steels of good quality are now made by overcoming the bad conditions of raw materials and refractory materials.

Development of Electric Furnaces

The range of the transformer capacity was 300-400 kVA./ton, but the recent practice tends towards utilizing higher voltage and larger transformer capacity aiming at quick melting.

In order to control electric fluctuation, the 'Amplidine' system is in use.

An electric induction stirrer is now studied for stirring the bath in order to obtain both the uniform chemical composition and good quality.

Basic Arc Furnace Process (Referring Constructional Steel and Case-hardening Steel)

(a) *Oxidizing Stage* — In the early stage until about 1945, active boiling by adding the ore was not in practice. But between 1936 and 1940 some light boiling practice was introduced, and after 1940 the violent boiling was carried out adding ore 20-30 kg./ton. Since 1951 the oxygen lancing has been applied to the melting, resulting in a success to produce low hydrogen content, good steel and low-carbon stainless steel.

(b) *Reducing Stage* — In the early stage until about 1935, reducing was controlled only by the carbide slag process. From about 1936 the white slag process was adopted. Since about 1940, the practice has changed to the following: After refining the oxidizing slags, a few deoxidizing materials, such as ferro-silicon, calcium-silicide and aluminium, are added in order to force the active deoxidizing reaction, then the slag is controlled to be white one of weak diffusion, thereby to refine the steel.

It is important to lower the content of hydrogen in steel to obtain sound ingots. It should be noted that the quick method of hydrogen analysis was invented by Japan Special Steel Co. Ltd. By this method they control the furnace practice in order to lower the hydrogen content under 9 cc./100 g. for medium and low-carbon or alloy steel and 14 cc./100 g. for 13 per cent Cr stainless steel. They are now obtaining good, sound ingots by the method.

Ingot Making

Exothermic hot-topping mixtures are used for the purpose of obtaining larger yield, and recently the electric arc hot-topping process is applied.

The continuous casting process, comprising William's process and Rossiyunghan's process, is now planned in some works in Japan.

It is important to eliminate the hair cracks or sand marks from steel. As it was found that the process of casting the ingots was partly responsible for this failure, the method of teeming practice is now studied.

Heat Treatment

The isothermal transformation diagrams ('S-Curve') are in use successfully for heat treatment, such as annealing, austemper, martemper, mar-quench and isothermal annealing.

For the surface hardening, gas carburization and the high-frequency electric induction heat treatment are now widely used. These methods make it possible for us to produce good, uniform products of low cost.

The 'sub-zero' cooling is applied for the heat treatment of bearing lathes, tools, etc. It can obtain the higher hardness, low strain and durability of the products.

Introduction

IN getting into the progress of special steel-making process in Japan, I would like to take up a subject on the change and development of special steel-making first and then to mention the progress of steel-making by electric furnace, ingot making and heat treatment method.

Change and Development of Special Steel-making Process in Japan

I roughly classified the period into four stages:

1st Stage — From the initial days when special steel-making was started in Japan to 1926 (the last year of Taisho Era).

2nd Stage — From 1927 (the first year of Showa Era) when the step of mass production was adopted by the gradually progressed method to 1937.

3rd Stage — From 1937 when the mass production was performed with the outbreak of the China incident to the end of World War II.

4th Stage — Postwar years.

1st Stage — It is said that the manufacture of special steel was originally started in 1740 by Benjamin Huntsmann living in the neighbourhood of Sheffield, England, who succeeded in making steel material for springs

of watch by the crucible furnace. In Japan, a German type crucible furnace was installed in the Navy Ordnance Depot in Tsukiji in Tokyo in 1882, and the manufacture of crucible furnace steel was started. As the materials, HŌCHO iron and TAMA steel produced in the Izumo and Iwami districts were used, and crucibles were imported from Morgan Crucible Co. in England. At that time, they were of the underground coke-fired furnace, and afterwards were changed to gas furnaces. In 1883, they succeeded in the manufacture of steel for saws and tool steel, and successively in the making of small calibre bullet and gun-barrels. Also, at that time, by combining a kind of clay produced in Owari with graphite in Hida, they succeeded in producing crucibles. Furthermore, parallel to the improvement of materials for crucibles and the progress of steel-making techniques, they came to supply high grade special steels and large ingots. Crucible furnaces and acid open-hearth furnaces were installed in Osaka Arsenal in 1889 and 1890 respectively, and quick-firing guns and small caliber bullets were manufactured in 1893 and armour-piercing bullets in 1894. In 1895, a small type acid open-hearth furnace was installed in Tokyo Arsenal, and it helped to expedite the progress in the manufacture of special steels for ordnance. Turning to the situation in Europe, research for special steel-making by the electric furnace had already been carried out. Since Henry Moison of France succeeded in the manufacture of alloy steel by electric furnace in 1890, the manufacture of alloy steels had been actively tried and various kinds of steels were contrived and newly supplied. Also, in 1898 Dr. Paul Heroult of France invented the Heroult electric arc furnace, and in 1900 he made the electric arc furnace for industry, which was the first step for steel-making by electric furnace for industry. In America, Crucible Steel Company of America, Syracuse, took the initiative in inviting Dr. Heroult to America in 1906 and started the

manufacture of special steels by installing the Heroult square electric arc furnace of single phase. Since then the United States has shown an extraordinary progress in this line. As the situation between Russia and Japan grew tense in 1904, Yawata Steel Manufacturing Works, in order to supplement the production of military arsenals, installed 8 crucible furnaces of 1200 kg. capacity and one gas-firing crucible furnace of 400 kg. capacity in 1905. Afterwards, the crucible furnaces were remodelled on the Siemen's gas furnaces, one of 600 kg. capacity and one of 1500 kg. capacity, and reached a monthly capacity of 150 tons of high-speed steel, tool steel, steel for gun-barrels, etc. Other furnaces were built in 1908. In the field of civilian business, Yonago Steel Making Works installed crucible furnaces in 1905, which was the first instance in the production of alloy steels. Also, acid open-hearth furnaces were installed in Kobe Steel Works and in Nippon Seiko (Japan Steel Works) in 1905 and 1907 respectively for the manufacture of ordnance. In 1908, Mr. Chobei Dobashi installed a small electric arc furnace in Matsumoto city for the first time in Japan and he started the manufacture of tool and cutlery steel. In 1911, a 200 kg. Heroult electric arc furnace was built in Yasuki Steel Works, and in 1912 Dr. T. Noda took the leadership in testing electric furnaces at the Naval Arsenal. Research in steel-making by electric furnace was conducted in building small type electric furnaces respectively in Yonago Steel Works in 1914, in Japan Special Steel Co. in 1915 and Atsuta Electric Steel Making Works in 1916. Japan Special Steel Co., having additional installation of two Siemen's type crucible furnaces of 1000 kg. and 1500 kg. capacity at that time, showed activities as a leading maker in the civilian field of steel-making. The output of special steel in Japan increased with the outbreak of World War I in 1914, which is shown in Table 1. However, in 1920 the postwar economic panic caused the unpre-

cedented depression, which drove many small iron and steel-makers to suspension of operations and top makers to deduction of funds. However, the influence was not so strong for special steel makers. Therefore, as you find, drop in the total production by both of the crucible and electric furnaces was mild as shown in Table 1, though a little decrease was indicated in 1921 and 1922. This was because the manufacture of aircraft was started in 1920. In parallel, special steel-manufacturing was spurred by the development of the automobile industry through progress of engine manufacture such as Hispano Suiza, Lorrain, etc., since the commencement of the production of Salmson's engines in 1917.

Special steel-making technique at that time was still crude. However, it was remarkably improved, since Japan Special Steel Co. manufactured steel for Salmson's engine in 1917. In 1919 the Research Institute for Iron, Steel and Other Metals was established in Tohoku Imperial University by Dr. Kotaro Honda, and it contributed much to special steel-manufacturing with a number of brilliant results in fundamental metallurgical research.

In 1919 and 1920 the production of high-speed steel, tool steel, constructional steel, etc., increased and the quality of the steels improved. However, it was still difficult to manufacture low-carbon steel like case-hardening steel. Adjustment of carbon content was very difficult due to increase in carbon quantity in the graphite crucible and efforts were made by applying clay lining inside of the crucible. However, it was still difficult. For this reason, necessity of an electric furnace for the manufacture of the said kind of steel was felt, which pushed them to study steel-making by electric furnace as mentioned above. Yawata Steel Works started the manufacture of silicon steel by electric furnace in 1924, which became the basis of self-supplying silicon steel sheet in our country.

TABLE 1—PRODUCTION OF SPECIAL STEEL IN JAPAN¹

YEAR	CRUCIBLE STEEL		ELECTRIC STEEL INGOT, tons	ROLLED STEEL, tons	IMPORT, tons	EXPORT, tons	REMARKS: Capacity of electric furnace in U.S.A. (tons)		
	No. of furnace	Ingot, tons							
Meiji	38	1905	—	—	—	—	—		
	40	1907	—	—	—	—	—		
	42	1909	—	—	—	—	—		
	44	1911	1	284	—	—	—		
Taisho	1	1912	—	662	—	—	—		
	2	1913	—	538	—	—	30000		
	3	1914	—	550	—	—	—		
	4	1915	—	1746	—	—	—		
	5	1916	—	4946	221	3137	—		
	6	1917	—	11476	3439	7296	510000		
	7	1918	31	8830	4329	8520	—		
	8	1919	29	6608	3670	9655	—		
	9	1920	—	1751	4233	2810	—		
	10	1921	51	2427	5195	12567	—		
	11	1922	51	2902	4531	5965	—		
	12	1923	—	1517	6292	7415	—		
	13	1924	30	797	11985	8877	—		
	14	1925	20	1204	15496	18905	—		
Showa	1	1926	26	2747	18159	10942	—	Max. 25 tons (excluding 80 tons of Timken)	
	2	1927	26	1175	26517	15929	2578		
	3	1928	26	1503	37746	18529	2790	—	
	4	1929	26	1778	52816	18429	2457	—	
	5	1930	26	1771	62140	13981	2419	—	
	6	1931	—	1536	52765	13931	1965	—	
	7	1932	—	2296	6940	27929	2396	—	
	8	1933	—	2191	139561	49524	7053	—	
	9	1934	—	1120	208790	57912	7074	—	
	10	1935	—	1200	241649	68832	10079	—	
	11	1936	—	1238	316475	85339	9673	—	
	12	1937	—	—	436444	155211	21813	—	
	13	1938	—	—	755687	257447	24662	1029000	
	14	1939	—	—	888588	389035	45740	209	
	15	1940	—	—	1083509	212377	23270	184	
	16	1941	—	—	1220709	319550	5553	747	
	17	1942	—	—	1419616	284440	202	160	
	18	1943	—	—	1686512 (719494)	463206	515	—	4629000
	19	1944	—	—	1852420 (781078)	636867	179	523	—
	20	1945	—	—	694074 (292843)	255965	101	142	—
	21	1946	—	—	390325 (73538)	66859	—	3	—
	22	1947	—	—	466906 (63388)	66845	—	1	—
	23	1948	—	—	554687 (98344)	85406	—	—	5329000
	24	1949	—	—	608288 (132486)	78686	2	59	—
	25	1950	—	—	752493 (139384)	80110	90	1564	—
	26	1951	—	—	931456 (260163)	158613	15888	1148	—
	27	1952	—	—	—	225715	3576	2527	—
	28	1953	—	—	—	305151	3570	3147	—

2nd Stage — In the 2nd stage, they were starting mass production by electric furnace, while decreasing gradually the steel-making by crucible furnace. As Table 1 shows, the annual production of special steel was close to 20,000 tons from 1925 and kept an upward curve. Installing more electric furnaces, makers responded to the increased demands with the development of heavy industries in Japan of automobile, aircraft, machinery, ball-bearing, electricity, shipbuilding, etc. The increase of furnaces in quantity and capacity was as follows:

1927, Daido Steel Works	10 tons Heroult Type (The largest one at that time)
1927, Yawata Steel Works	6 tons
1928, Kobe Steel Works	6 "
1928, Yawata Steel Works	6 "
1932, Kure Arsenal	30 "
	(Largest in Japan)
1932, Amagasaki Steel Works	10 tons
1933, Sumitomo Metal Industry Co.	15 "
1933, Japan Special Steel Co.	15 "

Special steel makers suffered from the influence of the 1931 depression. They, however, took a prosperous turn in 1932 and 1933. Only ten makers were engaged in the special steel making till 1931. However, twenty makers were newly added and Nihon Kako Co. and others were counted when the Manchurian incident broke out in 1931. Thus the manufacture of special steel became more prosperous.

3rd Stage — As Table 1 shows, production of special steels rapidly increased owing to a sudden demand of the steel for the military supply required by the outbreak of the war between China and Japan. For the necessity of good quality by mass production, scientific and technical research became

active. In 1934, research in manufacturing special steel was started under Dr. Kuniichi Tawara who was selected as chairman of the 19th Sub-Committee of the Japan Society for the Promotion of Science. His achievements in the research applied to practical operations were conspicuous, bringing about the improvement on the method of manufacturing special steels. The type of electric furnaces installed in the stage was larger than in the previous stage. They were between 8 and 20 tons, and 10-15 tons occupied the main portion. Top production of special steel was made in 1944 during the period of World War II, totalling 2,258,000 tons comprising acid open-hearth steel and electric furnace steel. Of the total, the electric furnace steel occupied 75 per cent, 1,538,000 tons by arc furnace and 155,000 tons by induction furnace, which shows the importance of electric furnaces for the production of special steel in Japan.

In the beginning of this stage, steels for ground ordnance, automobiles (the production of 30,089 ea in 1939 rose to 43,878 ea in 1941), and tanks were mainly produced. However, after the middle of the stage production force was directed to steels for aircraft. Various kinds of steels then in mass production were ball-bearing steel, nitriding steel, silicon steel, heat-resisting steel, high-speed steel, etc. (see Table 2). Also, with difficulties in obtaining alloys like W, Ni, Co, etc., after the middle of the China incident, research on substitute steels, especially on steels to save Ni, was earnestly made. Si-Mn-Cr, Cr, Cr-Mo, and low Ni-W steels were gradually adopted and rapidly used with the outbreak of World War II. Needless to say, it was met with much difficulty in use. However, it was the result of endeavour of learned men and engineers to surmount the difficulty and convert most of constructional steels to substitutes. It is all owing to the hard endeavour during the war that Cr steel, Cr-Mo steel, etc., are used at present, being adopted in JIS standard.

TABLE 2—THE PRODUCTION OF SPECIAL STEEL²
(Tons)

KINDS	YEAR							
	1931	1932	1933	1934	1935	1936	1937	1938
Alloy tool steel	487	497	505	732	1120	1180	1439	7824
High-speed steel	233	296	346	562	706	1315	1865	2062
Ball-bearing steel	214	257	358	501	758	820	972	1514
Heat-resisting steel	67	80	94	164	169	219	362	681
Nitriding steel	15	30	48	602	622	765	2197	4081
Stainless steel	324	661	748	838	984	1860	3882	4512
Other alloy steels	12762	19733	26696	37203	8737	47178	62107	114059
Alloy steels, total	14102	21454	28795	40602	13096	53337	72824	134733
Carbon steel	8800	25676	42681	47896	42673	46638	43378	60743
TOTAL	22902	47130	71476	88498	55769	99975	116202	195476

KINDS	YEAR						
	1939	1940	1941	1942	1943	1944	1945
Alloy tool steel	12574	19965	12315	19076	24871	21737	4491
High-speed steel	2930	2723	1715	1737	1693	1046	153
Ball-bearing steel	3036	6486	14498	21644	29254	29021	6018
Heat-resisting steel	939	631	1315	2070	3107	4033	899
Nitriding steel	7247	8675	11154	14829	30144	37419	7124
Stainless steel	5556	6845	8453	9898	13293	15781	2874
Other alloy steels	127040	166572	212473	282910	370702	399823	80297
Alloy steels, total	159322	211897	261923	352164	473064	508860	101856
Carbon steel	96313	108149	102051	140209	255842	339509	79308
TOTAL	255635	320046	363974	492373	728906	848369	181164

It is to be noted that a melting method to save Mn, one slag process, a special process of ingot casting, 'coating cast', by using fusible slag, etc., were studied during the war, which may be for your reference.

4th Stage (from the end of the war to the present) — Production during the four years after the end of the war was very low for the reasons that the demand for special steel decreased and, moreover, the military stock during the war was placed on the market (see Table 3). However, production was going up again from 1951 with bulky demand for automobile and vehicle coming in the Allied Forces with the outbreak of the Korean war in June 1950, leading to briskness of such kinds of industries as machinery, chemistry, shipbuilding, etc., decrease of the

military stock sent to the markets as mentioned above, and requirement for high grade and good quality of steels (see Table 3). Production of case-hardening steel for automobiles and high-tensile alloy steels was chiefly made. Research for boron-treated steel was pushed and also super-high grade and high-alloyed heat-resisting steel was studied and tried to manufacture with much attention after the war. It is time now that Japanese special steel makers should make more efforts for promoting study and technique, reducing the cost through rationalization and improving the quality. The recent situation of electric furnaces used mainly for the manufacture of special steels in Japan as of 1954 is shown in Table 4.

TABLE 3 — THE ROLLED SPECIAL STEELS AFTER THE 2ND WORLD WAR³
(Tons)

KINDS	YEAR				
	1949	1950	1951	1952	1953
Tool steel	16305	15655	25869	28351	35678
Constructional steel	23628	25348	74113	114116	173932
Steel for special use	38753	39107	58601	83248	95541
TOTAL	78686	80110	158583	225715	305151

TABLE 4 — RECENT STATUS OF THE ELECTRIC FURNACES (1954)⁴

KINDS	RATED CAPACITY, tons/year					NUMBER OF FURNACES				
	On work	Stopped	On repair	On erection	Total	On work	Stopped	On repair	On erection	Total
Arc furnace	1106380	102480	172900	13300	1395060	142	20	25	3	190
Induction furnace	143610	10690	8950	—	163250	75	9	6	—	90

Progress of Electric Furnace

The author has mentioned the increase in electric furnace capacity and the periodical change in the production in the previous chapter, and is going to take up electric furnace itself. In 1940, furnaces having kVA. 300-400 and maximum voltage 240 per ton as shown in Table 5 were generally in use as the standard.

TABLE 5 — ELECTRIC FURNACE CAPACITY AND TRANSFORMER IN JAPAN⁵

FURNACE CAPACITY, tons	TRANSFORMER CAPACITY		SECONDARY VOLTAGE	
	kVA./ton	kVA.	max. V.	min. V.
3	400	1200	160	69
6	400	2400	170	75
8	350	2800	180	81
10	350	3500	180	81
15	300	4500	180	81
20	300	6000	200	92
25	300	7500	200	92
30	300	9000	220	104
40	300	12000	240	104

It is beneficial to supply high power input in use of a large capacity of transformer and high voltage, which will bring shortening of melting hours and lowering of the fundamental unit of electric power consumption. It is already adopted in France and England; that is, they used a transformer of approximately 750 kVA. for 3-10 ton furnaces around 1915. However, they adopted 3125 kVA. for even 3 tons and 5000-7500 kVA. for 10 tons in 1929. Figs. 1(a) and (b) show lowering of fundamental unit and increase in production caused by high power input.

The standard capacity and electric equipment of Lectromelt furnace manufactured in Japan recently are shown in Table 6. The instance in the U.S.A. is shown for reference in Table 7. In our country, some of the makers installed 5-8 ton furnaces in 1952 and have since been engaged in production. Part of the results is published as shown in Table 8. There is a problem to study more on the subjects as to the life of furnace and whether or not the dephosphorization is carried well in performing rapid melting with high voltage for smaller furnaces than 10 tons in manufacturing special steels under the condition

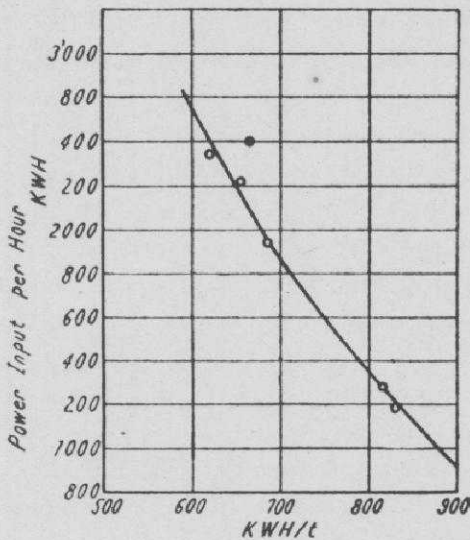


FIG. 1(a) — RELATION OF POWER INPUT TO POWER CONSUMPTION PER TON

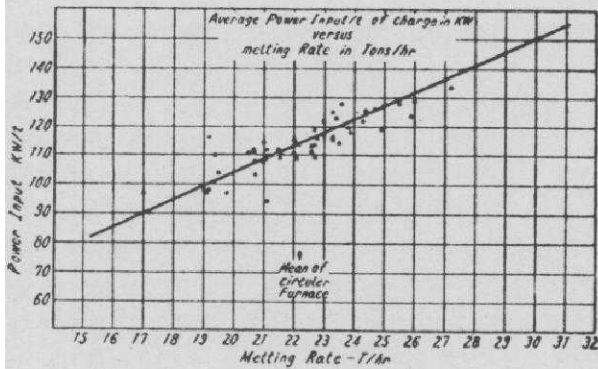


FIG. 1(b) — RELATION OF POWER INPUT TO MELTING RATE (JAMES K. PRESTON)

of Japan, which lacks for raw materials and fire-proof materials. The author calls your attention to the method of rapid melting with increased power input and higher voltage than usual, though lower than that of Lectromelt, which method is considered free of trouble about dephosphorization or damaging furnaces.

Top-charge Furnace — The top-charge furnace, being discussed from 1935, was adopted in 1937. However, the expected development was not influenced by the shape and quality of scrap in Japan. The number of top-charge furnaces occupies approximately 12 per cent of the total electric

TABLE 6—STANDARD FURNACE CAPACITY AND TRANSFORMER CAPACITY OF LECTROMELT FURNACE

CAPACITY, tons	TRANSFORMER, kVA.	MAX. SECONDARY VOLTAGE, V.
1	1000	210
2	1500	215
3	2000	220
5	3125	230
8	3750	230
10	5000	240
15	6250	260
20	7500	270
30	9375	285
50	15000	330
75	20000	385
100	30000	460

TABLE 7 — FURNACE CAPACITY AND TRANSFORMER CAPACITY IN THE U.S.A.

CAPACITY, tons	TRANSFORMER, kVA.	CAPACITY, tons	TRANSFORMER, kVA.
6	2700	60	12500~20000
15	4500~10000	70	15000~20000
25	10000~20000	—	—

TABLE 8—COMPARISON OF LECTROMELT FURNACES TO COMMON TYPE FURNACES

ITEM	KIND OF FURNACE	
	Old type	New type
Transformer (kVA.)	2500~3000	3750
Secondary voltage (V. max.)	180	230
No. of taps	6	12
Amplidine	none	use
Charging (h-mn)	45	5
Oxydizing period (h-mn)	2~0	1~10
Slag off and refining (h-mn)	2~10	1~50
Repair (h-mn)	10	10
Total time (h-mn)	5~5	3~15
kWh./ton	750	600
Electrode kg./ton	9	6
Labour (man)	8	3

furnaces as shown in Table 9, and those used for special steel only 4.6 per cent. However, the recent tendency is towards adopting this type again.

TABLE 9—THE NUMBER OF TOP-CHARGE AND SIDE-CHARGE FURNACES IN JAPAN (1954)⁶

TYPE OF FURNACE	FOR COMMON STEEL	FOR SPECIAL STEEL	TOTAL
Top-charge	35	22	57
Side-charge	257	168	425
TOTAL	292	190	482

Automatic Electrode Control System — Since the end of the war, many companies are going to adopt the Amplidine method as an automatic electrode control system. It needs more than 0.5 second in order to counter the change of arc with balanced-beam relay. However, it is made within 5 cycles in use of the Amplidine generator, which takes effect making easy operation.

Induction Stirrer — The induction stirrer is cited as one of the things to improve electric furnaces in future. This is a stirring apparatus made under the theory of induction motor by Prof. Ludwig Dreyfus who completed it after ten years of research. Installation of the apparatus in a 15-ton electric furnace was made for trial to move steel bath to the direction parallel to furnace bottom at Uddeholm plant of the Hagfors Co. in Sweden in 1948. Attention has been called to the publication that good results were obtained from installation of the apparatus in a 100-ton electric furnace 20 ft. long in Timken Co. of America in 1952. It is not realized in Japan as yet. However, it would materialize soon, as some companies have been studying.

High-frequency Induction Furnace — This furnace was made by E. F. Northrup in 1916, and 500 kg. furnace was imported to our

country for the first time by the Japan Special Steel Co. in 1931. Since the time the number of the furnace had been increasing, especially rapidly since the war between China and Japan. At present Japan is one of the leading countries with the number of the furnace. The furnaces are used for melting tool steel, high-speed steel, high-alloy steel and heat-resisting steel. As of 1954, there were 67 ea of various kinds of generators from 167 kW. to 1225 kW. and 164 ea of the furnaces in Japan, and the annual melting capacity is 77,520 tons. No progress is observed in high-frequency induction furnaces. However, it is to be mentioned that 12-ton furnaces have already been operated in Sweden.

Steel-making Method by Basic Electric Arc Furnace

Melting Method for Constructional Steel and Case-hardening Steel — Observation of the progress of melting method by basic electric arc furnace can generally be made in four stages. The 1st stage is from the first time to 1935, the 2nd stage to 1938, the 3rd stage from 1939-40 to 1950, and the 4th stage is from 1951 to the present. The 1st stage is the beginning of steel-making by the basic electric arc furnace, and the furnace itself was in the way of development. As to the melting method, it was weakly oxidizing and carried no oxidizing boiling in this stage. And, according to the condition of the furnace, some iron ores or scales were added in order to aid decarburization and dephosphorization, and carbon content in the final stage of oxidization was down to 0.05-0.10 per cent, even with constructional steel. Consequently, oxidizing stage took a pretty long time. In the deoxidizing stage, strong and diffusible deoxidizing method was adopted. The carbide method with carbon powder for adjustment of slag and deoxidization was mainly applied. It was difficult by this method to gain killed and clear steel, as it

lengthened the deoxidizing stage and lowered the temperature caused by the endothermic reaction which resulted in an increase of absorbing gas and insufficient removal of non-metallic inclusions.

It is in the 2nd stage from 1935 to 1938 that the boiling method was applied. Adequate ore (10-20 kg./ton) was used after melting down, and the rate of decarburization showed the extent of 0.002-0.004 per cent. They came to remove phosphorus thoroughly, being careful of over-oxidization in oxidizing stage, making adjustment of Mn so as not to go down below 0.2 per cent, keeping minimum carbon content at 0.1-0.15 per cent and the CaO/SiO₂ ratio of slag in 2-3, and performing removal of slag two to three times. The carbide slag, which was made with carbon and lime, was used at the beginning of the deoxidizing, and it was gradually changed to white slag in order to finish the process. However, there were already some companies at that time going to apply strong deoxidizing method of using small quantity of deoxidizing agents like Al, ferro-silicon or calcium silicide just removing slags. Since the time, research for snowflakes and non-metallic inclusions was actively made, and study on melting method was also developed accordingly.

Since 1939-40, special endeavour was made for improvement of quality. As a result, effect was brought on strong oxidizing process showing violent boiling with 0.004-0.005/min. of decarburizing speed using 20-30 kg./ton ore and adjusting the CaO/SiO₂ ratio of slag in 2.5-3.0. Generally in the beginning of deoxidizing stage strong deoxidizing was performed with Al, ferro-silicon or calcium silicide separately or with combination of all of them, and with the aim to keep the CaO/SiO₂ ratio of slag in 2.5-3.0 and FeO in 1 per cent maximum, the method to finish with white slag was adopted. For the 4th stage from 1951, steel-making method by lancing of oxygen was used. The method by lancing of oxygen was actually used to open-hearth furnace from 1949 after trial

for a few years since 1946. However, it was since 1951 that the method was operated in electric arc furnace steel-melting process. In blowing oxygen approximately 0.4 cubic metres/min./ton, though different from the quantity of oxygen blown, the decarburization speed in the blowing time shows 0.025 per cent C/min. after the completion of the blowing of oxygen decarburization speed becomes 0.007 per cent C/min. max. for 10 minutes, after another 10 minutes the drop is stable at 0.001 per cent C/min. — which proves the excellence of this method over the conventional one of ore (average decarburization speed, 0.006 per cent C/min. in oxidizing stage). Standard operation is kept in 4 cubic metres of flow quantity, approximately 5 minutes of blowing time and 2.5-0 cubic metres/ton of oxygen quantity blown, not over 5 cubic metres/ton, and is adjusted with a little higher basic degree of slag than in the method by ore. Owing to the rapid decarburizing speed as mentioned, the time of oxidizing stage can be shortened, and according to the improvement of smelting effect, exclusion of hydrogen is performed effectively. Especially in the case of melting of stainless steel it shows remarkable effects such as keeping good yield of Cr, raising utilization percentage of return scrap of stainless steel, and making manufacture of low-carbon stainless steel easy. But special variation is not found in the reducing period.

The author is going to mention in short chemical analysis, gas analysis, high temperature measurement and spectrum analysis which have the closest relation to progress of melting methods.

By the 19th Sub-Committee of the Japan Society for the Promotion of Science, established in 1934, research for cause and prevention of defects of special steel, especially for investigation of cause and prevention or removal of snowflakes and non-metallic inclusions, was made. The segregation of steel, thermal strains caused by heating and cooling, strains by transformation effects of

hydrogen, etc., were recognized to be the cause of generating snowflakes, and devices for cooling were carried out in actual operation. However, it is necessary to study the melting method itself. For the reason the research for nature, action, variation, and origin of non-metallic inclusions, oxygen, and hydrogen, which were the main factors to make sand marks, was performed under the leadership of the 19th Sub-Committee mentioned above. Parallel to this, research and standardization of analysis method of non-metallic inclusions, gas analysis method, high temperature measurement method, and testing methods (macro, sand marks, austenite grain size, etc.) were made. It may be no exaggeration to say that analytical technique of hydrogen resulting from the research in our country is more excellent than in foreign countries. Research for action of hydrogen in liquid steel has been actively carried out in our country and good result has been shown. It has been recognized since several years ago that it is difficult to obtain the sound ingot with more than 9 cc./100 g. hydrogen content in liquid steel in the case of low-alloy steels and with more than 14 cc./100 g. in stainless steel with 13 per cent Cr. This coincides with the result of Dr. Barraclough of England published recently as shown in Table 10. It is acknowledged that production of better ingot is made with higher rate at present, using lime with possibly a little amount of water contained, performing operation to prevent invasion of water possibly, taking adequate treatment after analysing hydrogen in liquid steel by the rapid analytical method of hydrogen devised by the Japan Special Steel Co. and by adjusting the amount of contained water lest it should be more than the amount mentioned previously. These operations have been pushed from the proof that hydrogen, the sources of which are the moisture contained in the lime additions and atmosphere, etc., rises after their additions into the reducing period.

TABLE 10 — APPROXIMATE HYDROGEN CONTENT IN LIQUID STEEL EXPECTED TO PRODUCE POROSITY AND WILDERNESS IN FULLY KILLED BASIC ELECTRIC STEEL (BARRACLOUGH)

TYPE OF STEEL	HYDROGEN CONTENT, cc./100 g.		
	Sound ingot	Porous ingot	Wild ingot
C steel	< 6.66	6.66~ 8.33	> 8.33
Low-alloy steel	< 7.22	7.22~ 8.90	> 8.90
Cr stainless steel	<10.00	10.00~13.20	>13.20
Austenite stainless steel	<13.20	13.20~13.88	>13.88

Calculated 1 p.p.m. = 1.11 cc./100 g.

It was impossible to get rid of incorrectness of measuring temperature of liquid steel, as the measurement was performed by only eye examination and optical pyrometer. However, possibility of adjusting temperature of liquid steel by immersion pyrometer, which makes direct and correct measurement, has led to adequate smelting. It is a matter of pleasure that not only steel quality is controlled but also research for steel-making method is carried out correctly and easily by the way.

On the other hand, in the light of the necessity of rapid melting operation forced by cut-down of cost and increase in demand for high-alloy steels and stainless steel, it is necessary to carry analysis of liquid steel rapidly and to adjust it quickly. For the reason that the rapid chemical analysis performed at present is not satisfactory to meet the above purpose, the spectro-analysis (for instance, by quantumeter or reading spectrometer) has recently been in use. In Japan 4 ea of the meters imported are under study. However, practical use of them will soon be realized with self-made meters.

Ingot Making — Exothermic Hot-topping: For the purpose of obtaining larger yield, various kinds of exothermic mixtures were

TABLE 11—HOT-TOPPING EXOTHERMIC MIXTURE

	CaSi	MnO ₂	SCALE	KNO ₃	CARBON POWDER	Mn ORE	FLUOR- SPAR	Fe-Si	Al	NaNO ₂	Al ₂ O ₃	MgO	CaO
1	41.0	20	30.0	9	—	—	—	—	—	—	—	—	—
2	41.0	20	30.0	—	—	—	—	—	—	9	—	—	—
3	55.0	—	35.0	—	—	—	—	—	—	10	—	—	—
4	30~40	—	50~70	8	—	—	—	—	—	—	—	—	—
5	35.0	20	27.0	6	10	—	—	—	—	—	—	—	—
6	25.0	—	50.0	—	10	—	5	5	5.0	—	—	—	—
7	30.0	—	50.0	—	5	10.0	5	—	—	—	—	—	—
8	45.0	—	45.0	—	—	10.0	—	—	—	—	—	—	—
9	47.5	—	47.5	—	—	5.0	—	—	—	—	—	—	—
10	50.0	—	40.0	10	—	—	—	—	—	—	—	—	—
11	40.0	—	50.0	10	—	—	—	—	—	—	—	—	—
12	55.0	—	40.0	5	—	—	—	—	—	—	—	—	—
13	50.0	—	50.0	—	—	—	—	—	—	—	—	—	—
14	13.0	—	68.0	—	—	1.5	—	—	17.5	—	—	—	—
15	10.5	—	54.5	—	—	1.0	—	—	14.0	—	10	5	5

studied and applied after 1935. The mixtures shown in Table 11 are typical ones of about 30 kinds in all. As the reaction of the mixture with thermit is not always good while that of Ca-Si is better, calcium silicide of approximate 50: 50 composition has lately been applied. It is reported that 14 and 15 in Table 11 are good.

Electric Arc Hot-topping Process — In 1935 the process was tested by Daido Seiko Co., but it did not diffuse so much. However, stimulated by the Kellog process which had shown good results in the U.S.A., some makers in Japan have adopted self-devised automatic or hand electric arc hot-topping process since 1951 and given good results. It is reported that the yield of ingot can be increased 5-10 per cent by this process.

Continuous Casting Process — There are two kinds, namely William's Process and Yunghan's Process. The continuous casting installations were established by some companies as follows for making industrial trial, and they have been showing good results:

1948, Allegheny Lundlum Steel Manufacturing Co., U.S.A. Rossi-Yunghan's Process

1950, Mannesmann Steel Manufacturing Co., Huckingen, West Germany

1948, Babcock & Willcox Tube Co., U.S.A. William's Process

It is reported that U.S. Steel Co., in Sheffield, England, is engaged in the manufacture of special steels, installing the Rossi-Yunghan's machinery in 1954. Also, it is said that Atlas Steel Manufacturing Co. in Canada will complete the installation of the Rossi-Yunghan's machinery in the near future and start actual production of alloy steels like tool steel, high-speed steel, stainless steel, etc. In Japan, Sumitomo Kinzoku Kogyo K. K. is installing Rossi-Yunghan's machinery with the technical co-operation of Continuous Metal Co. and is expected to complete it in October of this year. If the process can produce ingots of good quality for high grade alloy steels by easy and continuous manufacturing, it is an epochal manufacturing method for bringing a great deal of benefits not necessitating either installation of blooming mill which requires colossal amount of capital or surface conditioning, but giving high yield.

Also, a few of our leading companies are interested in the process and are currently studying it.

Prevention of Sand Marks — Sand marks which appear during machining steel materials are fatal, and learned men and engineers have been endeavouring to prevent the sand marks for many years. To prevent sand marks of case-hardening steel, manufacture of the said steel was put under research from July 1949 by the Japan Iron & Steel Association, the chairman of which was the author, and, through the observation of the result that sand marks were often found in steel in spite of no marks observed during the melting process performed under determination of operational standard, it was found that many factors after pouring out have close relation to the generation of sand marks. Opinions have been raised insisting that generation of sand marks was caused by deoxidizing in ladle, by erosion of ladle bricks, by deoxidizing products of solidifying ingot, etc. These, of course, are reasons. However, existence of other important factors like oxidization by air touched during the pouring was recognized, which led to the conclusion that further development of research on the subject should be made. At present research is being widely performed at the places concerned, and it is expected that ways for solution would be opened in the near future.

Progress of Heat Treatment of Special Steel

The main phases of progressed heat treatment for these years appear in the methods applied by S-Curve, gas carburization for surface hardening, high-frequency induction heating and sub-zero cooling method.

S-Curve and Its Application — Since the research for isothermal transformation of steels was made public for the first time in 1930 by E. S. Devenport and E. C. Bain, study of isothermal transformation develop-

ments of various kinds of steels was made also in our country, and many diagrams of the isothermal transformation, so called as S-Curve, were submitted.

Heat treatment heretofore applied is the continuous cooling method to make cool from high temperature to room one, and it makes both of annealing and hardening in accordance with cooling speed; that is, it is the heat treatment to cause transformation by continuous cooling. However, the following heat treatments applied by the isothermal transformation are carried out at present according to different purposes:

- (1) Isothermal annealing
- (2) Isothermal hardening:
 - (a) Austemper
 - (b) Martemper
 - (c) Marquench
- (3) Isothermal tempering.

The isothermal transformation heat treatment has recently been applied to a great extent with much benefit to shorten heat treatment hours, to strengthen products, to prevent cracks and to improve cyclic operation of furnace which would not be gained by the continuous transformation heat treatment.

Gas Carburization Heat Treatment — It is suitable for mass production of small parts, and is possible to perform continuous operation from carburization to quenching. The following are the benefits brought by this method:

- (1) Possibility of continuous operation.
- (2) Possibility of automatic quenching.
- (3) C per cent of carburized layer is easily adjusted.
- (4) Uniform carburization can be made.
- (5) It is easy to adjust thickness of carburized layer.
- (6) It is possible to shorten carburization hours.
- (7) Operational environment is greatly improved and man-hour cost is cut down.
- (8) It makes operational cost cheap.
- (9) Products of good quality can be gained.

For the reason that it is specially fit for carburization of small gears and ball-bearings, it is widely used in the line of the said products. Natural gas, water-gas, propane (C_3H_8) or butane (C_4H_{10}) are used as material gas. Gas, made with a mixture of air and the material gas through catalytic action with charcoal, Ni, or other things and adjusted for neutralizing or weakly carburizing, is used as the gas called diluted gas or carrier gas. It is said that 20-40 type gas mentioned below is standard.

CO	H ₂	N ₂	CH ₄	CO ₂	H ₂ O
%	%	%	%	%	%

10-20 35-55 14-45 0.5-1.5 below 1 below 1

As up-to-date continuous gas carburization furnaces are manufactured in Japan and can be obtained with low cost at present, the treatment has been widely utilized.

High-frequency Electric Induction Heat Treatment — The first instance in Japan was set in 1938, when Akashi Plant of Kawasaki Aircraft K. K. applied high-frequency electric induction heat treatment by the Tocco method for surface hardening of the pin part of the crankshaft of B.M.W. engine. Having been applied for several years for surface hardening of piston rod, crank pin, surface of shaft, tooth of gear, rail, etc., it is making rapid progress. The characteristics of the method are as follows:

- (1) It makes hardening expense low.
- (2) As it is short-time heat treatment, no decarburization is made and oxidization of the hardened surface is extremely little. Consequently, grinding operation after hardening is omitted, just through the process of machining-heat treatment-final finish-quenching.
- (3) A little strain is observed, as it is not fully quenching.
- (4) Because of direct heating, heating efficiency is good.
- (5) Operational process is carried exceedingly efficiently.

- (6) It is unnecessary to prevent carburization.
- (7) Surface hardening is high.
- (8) It is all right with material with 0.45 per cent or low-alloy steel.

In accordance with the depth of surface hardening layer, selection of electric cycle can be adjusted between 3000-10,000. For the reason that excellent high-frequency generating apparatus such as mercury arc oscillator type, spark gap type, vacuum tube oscillators type, which compare with the ones in foreign countries can be obtained with low cost now in our country, application of the method has rapidly increased. Electric source, cycle and approximate cost are shown in Table 12 for reference.

TABLE 12 — HIGH-FREQUENCY ELECTRIC SOURCE, CYCLE, CAPACITY AND APPROXIMATE PRICE

ELECTRIC SOURCE	CYCLE	CAPACITY, kW.	PRICE, \$/kW.
Motor generator	500~10000	100~1000	230~100
Spark gap type converter	10~200 kC.	20~50	270~180
Vacuum tube Oscillators type	200~500 kC. 1 MC. up	2~200 0.2~10	600~350 1000~500*

*20~40 MC.

Sub-zero Cooling — This treatment aims to decrease the remaining austenite of the quenched steel to low temperature below 0°C. The characteristics are as follows:

- (1) High and uniform hardness can be obtained after sub-zero cooling through quenching.
- (2) It decreases inside stress of quenched steel and increases toughness.

It has recently been applied much for high-speed steel tools (drill, hacksaw, tap, hob, broach, etc.), ball-bearing made by Cr steel with high carbon, carburized gear, magnet

steel, and cold fitting. Taking an instance of high-speed steel, S. M. Depoy published the result that the life of tool bits made by various kinds of high-speed steels showed 41 per cent increase under application of the cooling method.

References

1. *Statistical Statements by Iron & Steel Control Association and by Iron & Steel Federation.*
2. *Statistical Statement by Iron & Steel Control Association.*
3. *Statistics of Iron & Steel in Japan, 1954, 53.*
4. *Survey of Equipment and Capacity for Iron & Steel Production, by Iron & Steel Federation in 1954.*
5. *Report III, by Research Committee for Electric Furnace Steel Making, Iron & Steel Institute of Japan, October 1940.*
6. *Survey of Equipment and Capacity for Iron & Steel Production, by Iron & Steel Federation in 1954.*
7. *Report I-VI, by 19th Sub-Committee, The Japan Society for the Promotion of Science.*
8. *Journal of Iron & Steel of Japan, 38(12) (1952), 42. Proceeding of the 1st World Metallurgical Congress, 1951, A.S.M. (1952), 247.*
9. *Journal of Iron & Steel of Japan, 40(4) (1954), 20.*
10. *Journal of Iron & Steel of Japan, 38(12) (1952), 71.*
11. *Trans. A.S.M.E., 66 (1944), 45.*

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