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DEVELOPMENT OF TIN PLATE MANUFACTURING IN JAPAN 1/

by

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Summary

This paper outlines the history and the development of tin plate manufacturing industry in Japan. The paper traces the sequence of development of the general tin plate production processes, beginning at the production the specific steel strip required and ending at the final tin plate of it. It then discusses the recent trend in tin plate properties, and ends by describing what is generally known as tin-free steel, new materials being increasingly used, in place of tin plate, for the production of cans, etc.

1. Introduction

The tin plate industry in Japan, which had been completely destroyed in World War II, has since made a spectacular progress after the war and particularly during the last fifteen years. The production of tin plate in Japan, in fact, is more than one million tons annually, making her rank third in this specific field of production, following only the United States and the United Kingdom.

Said achievement has been made possible by the construction in Japan of the most up-to-date facilities for the manufacture of tin plate after, and thanks rather to, their complete destruction by the war, and, on the other hand, by the rapid development of the metal-container industry in Japan.

The reader will perhaps be interested in knowing that, although basically tin plate manufacturing in Japan is dependent on western technologies, we ourselves too have contributed greatly towards producing low-cost and high-quality tin plate, as a result of consistent researches we have carried on along the entire process sequence of tin plate manufacturing.

Our contributions towards development of new manufacturing techniques have bearings not only on tin plate as such but also on metal-container materials in general.

This paper, to begin with, traces the general development of tin plate manufacturing techniques in Japan, sequentially from iron-making to tin plating, and describes the general properties of the products obtained from time to time. But it does not cover what may be considered standard operations such as can easily be learned from practically any textbook of tin plate production. Tin-free steels, that are by far the newest materials for cans, will lastly be described briefly.

2. History of tin plate in Japan

The history of tin plate industry in Japan began when the Yawata Works of the present NSC manufactured hot-dipped tin plate in 1923.

Although tin plate production by the hot-dipping process reached 190,000 tons in 1938, the industry was completely destroyed in World War II.

Most substantial increase in the production of tin plate in Japan, however, was witnessed after the war, and especially after electrolytic tin plate began to be manufactured in 1955. Figure 1 shows the growth of the tin plate production in Japan.

A brief chronology of the tin plate industry in Japan also is shown in Table 1.

3. Demand and supply of tin plate

Demands for tin plate in 1968 were as shown in Table 2. It may readily be seen from this table that exports accounted for forty-four per cent of Japan's total production. More than ninety-five per cent of the domestic consumption of tin plate, on the other hand, went into containers of the types shown in Figure 2.

In recent years the ratio of food cans to the total number of containers made has shown a tendency of decreasing, whereas that of non-food cans has tended to increase. Principal food-can products and their ratios are shown in Figure 3. Although the greater part of the preserves to be packed in food cans is either fish or fruit, juices and other beverages have also shown a remarkable increase. To meet such demands, the production of tin plate has increased tremendously, as shown in Figure 1. For reference, demands for metal cans in the United States, and world production and consumption of tin plate are shown, respectively, in Tables 3 and 4.

4. The development of tin plate manufacturing techniques

Inasmuch as over ninety-nine per cent of tin plate material is steel, the performance quality of tin plate in general is greatly affected by the quality of the base steel itself.

Considering from this point of view, it will be quite natural that the development of tin plate manufacturing techniques in Japan should be explained in terms of the sequence of operations starting at the blast furnace.

4.1 Iron- and steel-making

For the sake of producing, at low prices, tin plate having minimum corrodibility and good formability, it is necessary not only to develop optimum tin plating technology but also to produce optimum iron and finally steel to go into tin plate as its base metal. Many innovations have in fact been developed and induced stability of operation, low coke rate and high productivity. Figure 4 shows the national average for productivity, that is, average daily iron output per cubic meter of inner volume of blast furnace.

The BOF process, using oxygen converters, in the meantime, has come to make better and much more economical steels. This process has been applied to base-plate manufacture for tin plate in Japan since 1958. Figure 5 shows the growth of production by BOFs in Japan, and now the ratio of steel made in them is more than seventy-seven per cent of the total production of steels in Japan.

4.2 Hot rolling and pickling

The hot rolling operations for the manufacture of tin plate base metal comprise rolling of ingots to slabs and continuous rolling to strip in coils.

We have in recent years introduced continuous casting for making slabs, although not quite on commercial bases yet, as a replacement for rolling from ingots.

Many reference literatures[1)] are now available as regards the effects of temperatures and reduction histories in hot rolling on the metallurgical qualities of steels produced by means of continuous casting.

The base-metal pickling process also is very important in respect to the quality of tin plate, because if said operations happen to be defective, pits, for example, are quite likely to appear on the surface of the steel strip thus treated. These pits, after cold rolling and tinning, might ultimately worsen the corrodibility of the tin plate produced therefrom.

4.3 Cold rolling

Cold reduction operations are generally undertaken in Japan on tandem mills. Needless to say that the process of cold rolling is a necessity from the point of economy because cold rolling, as a matter of basic principle, is aimed at high-speed operations. Automatic gauge controls are being employed to realize said high speed operations, and they have greatly contributed towards stabilizing the thickness of the resultant tin plate base metal.

4.4 Annealing

For the annealing process, it is necessary to satisfy two main objectives: firstly, control of the heating cycle to make it follow a predetermined optimum pattern, and, secondly, control of the furnace atmosphere to prevent oxidation, discoloration and staining of the strip being annealed. As regards development of annealing in Japan, said former objective has been realized by adopting continuous annealing lines ever since 1959, whereas the latter, by improving the annealing atmosphere.

By using HNX gas in place of DX gas in the batch annealing furnace since 1955, for example, tin plate thus produced has come to obtain superior corrosion resistance, especially along coil edges, as shown in Figure 6. It may well be pointed out at this juncture that differences in corrodibility of tin plate base metal are generally recognized to be mainly dependent on the extent of etching of the steel surface by the annealing atmosphere.

It was indeed for this reason that HNX gas has been prepared from cracked ammonia gas and nitrogen by-product of an oxygen plant, to ultimately make the annealing atmosphere more stable and more economical.

4.5 Skinpass and double reduction

Double-reduced tin plate has been produced in Japan since 1962, at first, each tin mill used double reduction mills which had been reconstructed from skinpass mills. During the course of the last few years, however, they have built mills for the exclusive manufacture of double-reduced tin plate.

Incidentally, the relationship between the cold-reduction ratio of steels and their hardness and tensile strength is shown in Figure 7. For double-reduced tin plate, said ratio usually is between twenty-five and thirty-five per cent.

4.6 Electrolytic tinning

Since the electrolytic tinning line was first introduced to Japan in 1955, the production ratio of the electrolytic tin plate has increased tremendously, and now a total of nine Ferrostan lines and one Halogen line are in operation.

These are currently producing more than eighty-eight per cent of the total production of tin plate in Japan.

In these operations the prepared strip steel is made to pass through electrolytic cleaning, electrolytic pickling, electrodeposition of tin, flow-melting thereof, passivation and oiling steps.

Developments of these processes in Japan may briefly be explained as follows:

For satisfactory electrolytic tin plating, and especially for the removal of lubricants on double-reduced plate base, the electrolytic cleaning section has been consolidated featuring dipping and brushing operations. Cleaning solutions, in the meantime, have been studied to ultimately develop in them the best possible cleaning properties.

The stability of the tin-depositing operation is an extremely important factor in the electrotinning line[2]. Improper plating-bath composition and operation thereof, for instance, would make it impossible to obtain optimum tin deposition. For this purpose, all available control methods have been investigated into. To preserve a stable and good productive plating solution, it has been found necessary to control the additive agent and surface tension together with the principal bath components. Checking of the condition of the plating solution by circulation plating cell has also been found important for maintaining stability.

By means of all these control techniques, tin-deposition operations, including differential coatings, have been kept stable over long periods of time.

The recent high-speed tin plating lines are currently employing the induction-and-conduction combination melting method to facilitate high-speed operations. Production of a continuous and compact alloy layer on the base-steel surface, on the other hand, is generally recognized as being a very important factor in improving the corrosion-resistance of the tin plate. For this purpose, optimum regular practice has been established throughout the entire manufacturing sequence of the base steel. Said production of a good alloy layer has of course a very close relation also to the operation of tin deposition[3)] and methods of its melting. Superior-quality electrodeposited tin, in the meantime, is melted by application of an electric current to the strip. We have recently learned in this connection that by using a little more current than is basically necessary to melt the tin, products of somewhat better qualities may be obtained.

Electrochemical treatment to passivate the tin plate surface is generally being employed. Cathodic treatment in sodium dichromate solution for this purpose has generally been found to be most satisfactory, and hence is being applied practically throughout the world.

The next operation in the electrolytic tinning line is deposition of an oil film on the surface of the end product. The surface oils used are mainly either cottonseed oil or dioctyl sebacate (di-ethyl hexyl sebacate or DOS). It is applied to tin plate surfaces by the electrostatic oiling method. Cottonseed oil, however, contains some unsaturated fatty acids, and, therefore, has a tendency to oxidize and polymerize. The oxidized materials, in turn, would sometimes prevent the enamel coating from completely wetting the surfaces and thereby would become the cause of eyeholes[4)]. The relation between storage time after oil film application and the tendency of eyeholes to form is shown in Figure 8.

When DOS weight and application is well controlled, it has been found to be relatively more stable than cottonseed oil, and compatible with practically all the usual types of enamel. But the viscosity of DOS is low, and hence its layer on tin plate surfaces is moveable. This physical property of the oil would sometimes pose a pudding problem on the tin plate surface, which is especially true in the case of coils. To solve this problem, DIDP (di-isodecyl phthalate), which is relatively more stable and therefore of suitable viscosity, has since been developed for use as a surface oil for tin plate, and NSC is now proceeding with its use in the commercial production of the product. DIDP, by the way, has since been duly approved for use on tin plate to be fabricated into food cans, by the Food and Drug Administration of the United States[5].

5. Properties of tin plate

Needless to say that tin plate has most attractive appearance, some unique electrochemical properties which make it remarkably corrosion resistant when fabricated into fruit cans; it has an excellent formability, and can be soldered with ease at high speeds. It is no doubt because of these excellent properties of tin plate that it is still so extensively used as a material for all sorts of containers throughout the world. In Japan, accordingly, tin plate is being produced strictly in accordance with standards established in many countries of the world to satisfy the demands of end users anywhere.

5.1 Appearance

No doubt the appearance of tin plate is related to the extent of roughness of steel base itself. It may well be noted, however, that, although bright-finished tin plate that having a steel base roughness of less than 10μ inch r.m.s. has hither to been most extensively used, stone-finished plate with a roughness around 15μ inch is recently being preferred because apparently of its lesser surface marrying during shipment and handling.

Beside the above matte-finished plate is commonly being used for crown caps, and tin plate with silver finish, for most art cans.

5.2 Mechanical properties

The most important of all the mechanical properties of tin plate is, of course, that classified by a system of numerical temper grades which have been established in the United States[6]. Depending, for instance, on the can size or its content, it is necessary to select a suitable thickness and temper grade of tin plate from which the can is to be fabricates. Generally, in case plate having one higher temper grade is used, the thickness of the plate may be decreased by five Lbs/B. B., and still will exhibit performance equivalent to what has originally been desired.

A typical instance of such decreased thickness of the steel base is the high-temper double-reduced tin plate.

Double-reduced tin plate, trade-named DR-10, for example, is being used quite extensively as the end stock of beer cans or those for carbonated drinks, where strength is an important factor. The steel comprising base of DR-10, however, happens to be quite expensive because of its added nitrogen and subsequent treatments required therefor.

For lowering the production cost of it, new method of manufacturing similar hard steel base are being investigated into, such as stress-relief annealing for the can end stock, etc., etc.

5.3 Corrodibility

The corrosion mechanisms of tin plate are so complicated as to have been investigated into by many researchers, but by far the most essential point perhaps is that under certain conditions tin becomes anodic to steel and thereby protects it "sacrificially" so to speak. Recently, however, following the expansion of tin plate usage, products in which tin does not product the steel base have come to be on the increase, and thus the corrodibility of the steel base itself has come to comprise an important factor. With tin being anodic to steel, it has become evident, in the meantime, that the layer of tin-iron alloy between the tin coating and the steel base is an important component of tin plate[3]. It is on bases of these factors that high corrosion-resistance tin plate, often called K plate, has been specified and produced commercially since 1962 in Japan, said K plate being produced by controlling alloy-tin couple values, iron solution values, tin crystal sizes and pickle-lag test values.

When, however, tin does no longer protect the steel, the rate of corrosion, especially perforation corrosion, of tin cans, comes to be related to the composition of the tin plate steel base itself, often making it necessary to coat the tin plate with a certain organic enamel. It may well be noted in this connection that there is a definite relationship between sulfur content of the steel base within normal limits and its corrosion resistance, especially in relation to the Cola-type carbonated drinks[7]. Such relationship is shown in Figure 9.

5.4 Solderbility and compatibility with enamels

Tin plate is often coated with enamels, so the degree of adhesiveness of the enamel so used is an important factor, which depends not only on quality of the enamel itself but also on the surface condition of the tin plate. Too much oxide film especially in the case of hot-dipped tin plate would sometimes cause poor adhesion. It is also important for the tin plate to permit complete wetting and coverage by its enamel coating.

Prevention of oxidation by means of oil surface-coating, as has already been referred to, is an important factor.

But by far the most important property of tin plate is perhaps its ability to be soldered rapidly and with great ease, thanks particularly to the recently development of high-lead solder and special fluxes to be used for soldering, capable of eliminating the greater part of the troubles experienced heretofore. Worth noting at this juncture is the fact that pretreatments of the steel base and passivation process in the tinning line have an important bearing on tin plate solderbility.

6. Tin-Free Steels

Lastly, but none the less important is the fact new materials other than tin plate are being extensively sought for can manufacture. To cope with the shortage of tin and the "strategic" nature of it steel producers in Japan, as well as in the leading countries of the world, have keenly been on the look for tin plate substitutes that would provide performance equivalent to that of tin plate as can materials.

The metallic-chromium-type tin-free steel has resulted from such efforts. Tin-free steel, or TFS, of a type being produced by NSC has double layers of surface coating. The under layer is metallic chromium and the upper is a hydrated chrome oxide. This coating system enables the plate to have excellent enamelling and corrodibility characteristics. The shipments of TFSs in the United States in 1969 amounted to a total of 560,000 tons, and more than ten per cent of the tonnage was used for the fabrication of containers of all sorts[8)].

Although TFSs cannot readily be soldered, in recent years two new can making processes have been developed to compensate for this shortcoming, and are now being used extensively in manufacturing cans at commercial speeds[9)]. One of these processes makes use of a certain type of thermoplastic cement, whereas the other employs electric welding.

Fully enamelled cans are increasing in usage, but the trouble is they prevent the dissolution of metallic ions, and for this reason use of TFSs, such as NSC's SUPERCOAT and CANSUPER, is expected to increase most remarkably in the very near future as new materials to be used for the making of all types of cans and containers.

7. Conclusion

The Japanese tin plate industry, which was destroyed completely in World War II, has registered an amazing growth firstly through the assistance of industrially developed western countries and now thanks to the internally-generated technological innovations.

Japan has thus come to be one of the leading tin plate manufacturing countries of the world.

As the iron and steel industry of Japan continues to devote efforts to research and development in fields referred to herein, there are reasons to believe that it will ultimately be able to achieve quite a significant role in introducing technological innovations not only to relevant industries of Japan but also to those of the world.

NSC, in particular, has endeavored to manufacture and offer good quality tin plate and TFS's as economical materials for the manufacture of food cans and other containers to satisfy the changing world demand for the preservation of food, beverages, etc., and will be more than glad to be of full service to end-users all over the world.

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Table 1. Chronology of tin plate in Japan

Year	Item
1923	Hot-dipped tin plate manufacture, started
1941	First continuous strip mill for tin plate, built
1955	Electrolytic tin plate manufacture, started
1957	BOF process for steelmaking, came into operation
1958	Continuous annealing line for tin plate, introduced
1961	Tin-free steel manufacture, started
1962	Double-reduced tin plate manufacture, started

Source: Nippon Steel

Table 2. Domestic demand and total supply of tin plate in Japan

(1968)

Usage	Hot Dipped	Electrolytic	Total
Industrial tools	1	2	3
Electronics	1	3	4
Office supplies	2	4	6
Containers	57	594	651
Miscellaneous	8	3	11
Total domestic consumption	69	606	675
Domestic sales	66	590	656
Export sales	68	440	508
Total Production	134	1,030	1,164

Source: J. I. S. F. (Unit: 1,000 tons)

Table 3

Metal Can Shipments by Base Boxes in the U. S. A.

	1967	1968	1968 Compared with 1967
METAL CANS:			
Total	133,980,000	145,862,000	8.9 Incr.
COMMODITY			
FOOD - BEVERAGE:			
Fruit & Fruit Juices	14,313,000	14,251,000	0.4 Decr.
Vegetable & Veg. Juices	21,952,000	24,541,000	11.8 Incr.
Evaporated & Cond. Milk	3,337,000	2,854,000	14.5 Decr.
Other Dairy Products	728,000	731,000	0.4 Incr.
Meat & Poultry	3,803,000	3,919,000	3.1 Incr.
Fish & Seafoods	2,920,000	2,833,000	3.0 Decr.
Lard & Shortening	1,986,000	1,696,000	14.6 Decr.
Baby Food & Formulae	855,000	870,000	1.8 Incr.
All Other Foods & Soups	13,277,000	13,509,000	2.1 Incr.
Total Foods	63,121,000	65,204,000	
Coffee	4,162,000	4,117,000	1.1 Decr.
Beer	27,537,000	30,684,000	11.4 Incr.
Soft Drinks	14,580,000	20,055,000	37.6 Incr.
Total Beverages	46,279,000	54,856,000	
PET FOOD	5,797,000	6,200,000	7.0 Incr.
PRESSURE PACKING (Valve Type)	4,371,000	4,751,000	8.7 Incr.
NON FOOD:			
Oil (Open top thru 5 Qt.)	3,056,000	3,166,000	3.6 Incr.
Paint, Varnish Products - Incl. Painters' Supplies	4,154,000	4,387,000	5.6 Incr.
Antifreeze	828,000	923,000	11.5 Incr.
All Other Non Food	6,374,000	6,375,000	.01 Incr.
Total Non Food	14,412,000	14,851,000	

Source: Can Manufacturers Institute Inc.

Table 4

Production and Consumption of Tin Plate

(1967)

(Long Tons)

	Production	Consumption
U. S. A.	5,349,400	5,225,000
U. K.	1,210,700	791,000
Japan	1,047,000	646,000
France	676,972	406,000
Germany	589,363	507,000
U. S. S. R. (e)	459,000	..
Canada	382,500	386,500
Netherlands	322,922	220,000
Italy	305,677	347,000
Belgium	225,107	88,000
Brazil	203,446	230,000
Mexico	127,253	120,000
India	78,000	140,000
World*	11,041,200	11,097,000

(e) = Estimated

* Totals in table related to Western World countries only.

Source: International Tin Council

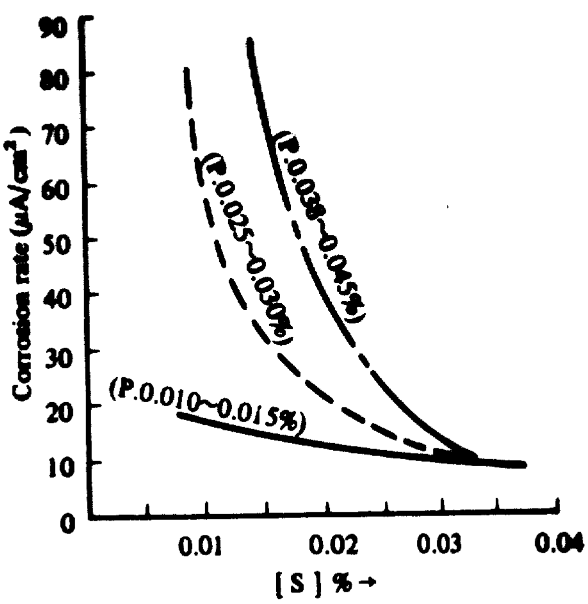
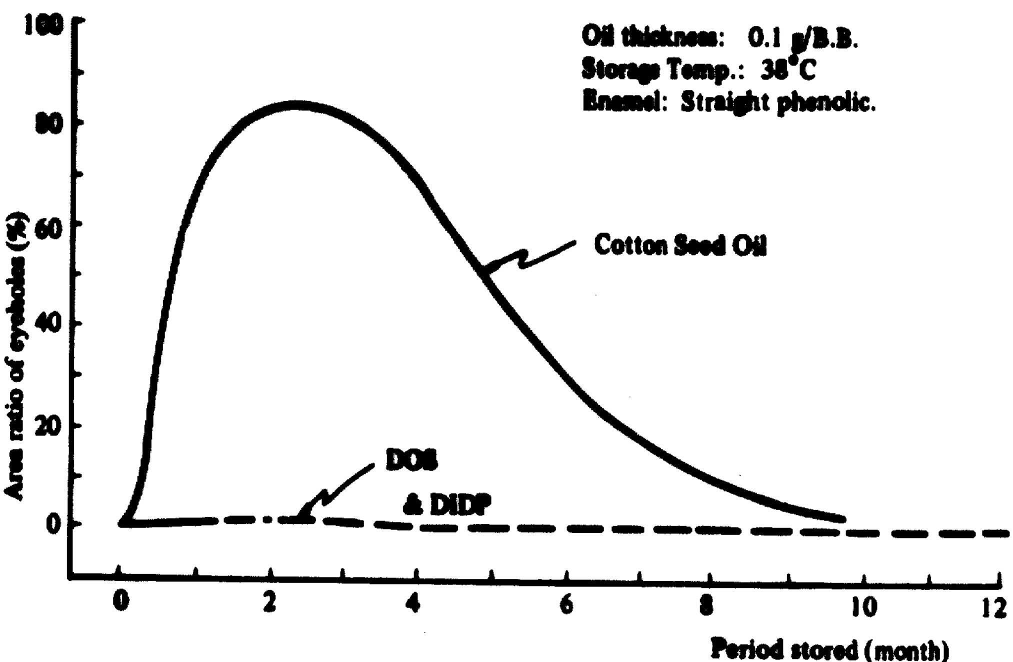


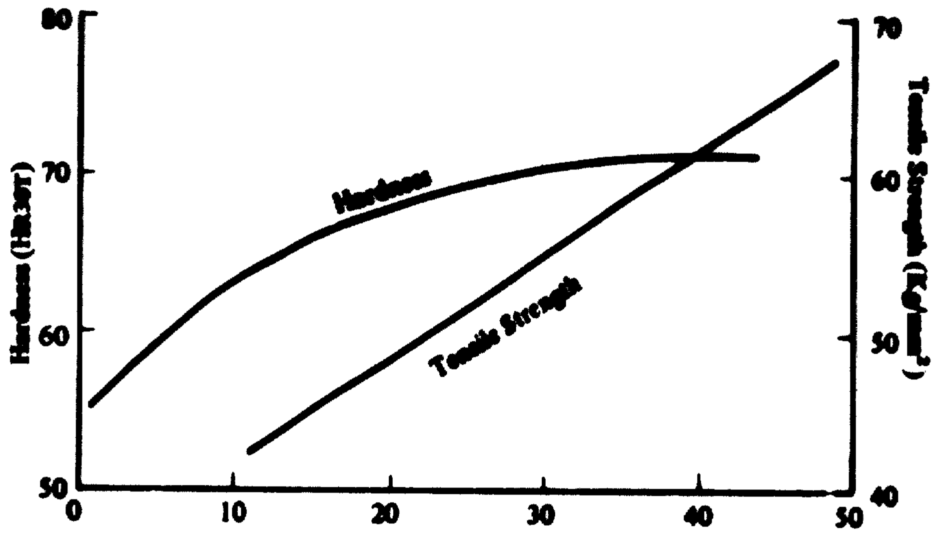
Fig. 9 **Relationship between sulfur content in steel and corrodibility in respect to Cola-type drink.**

Source: JISIJ 55 (1969) No.3.



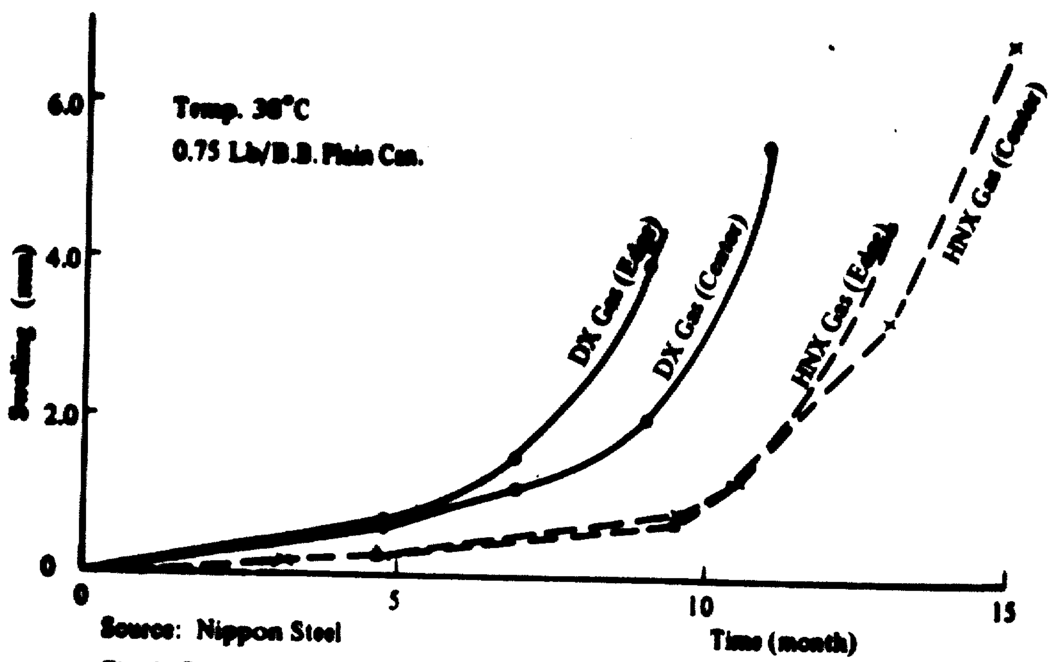
Source: Nippon Steel.

Fig. 8. Relationship between periods stored and tendency of eyeholes to grow on tin plate.



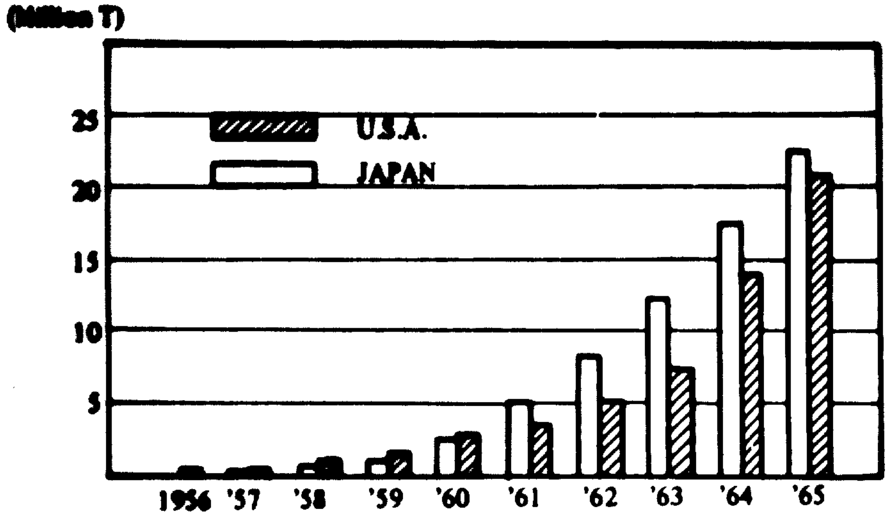
Source: Nippon Steel Reduction ratio (%)

Fig. 7. Relationship between reduction ratio and hardness.



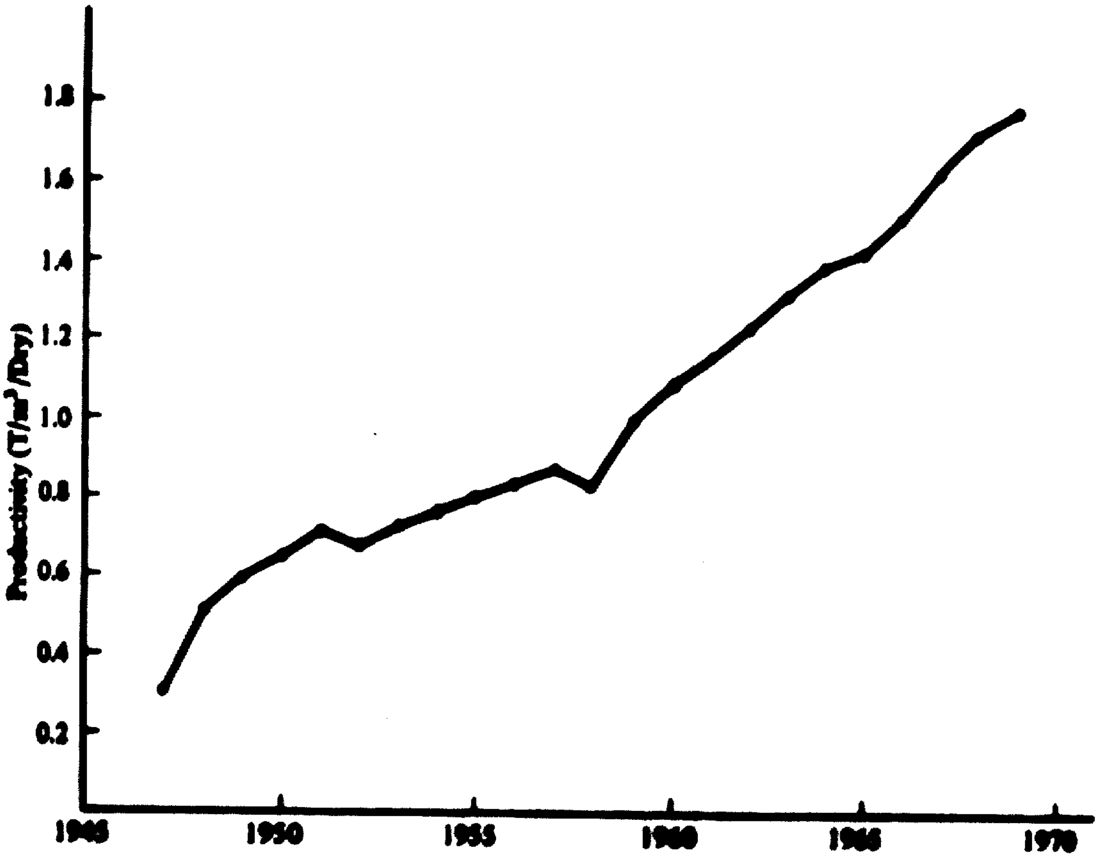
Source: Nippon Steel

Fig. 6. Pack tests made in respect to mandarin oranges



Source: J.I.S.F., I. & S. Engr. (Jan. 1966)

Fig. 5. Annual Production of BOF Steel



Source: J.I.S.F.

Fig. 4. Productivity of Blast Furnace in Japan

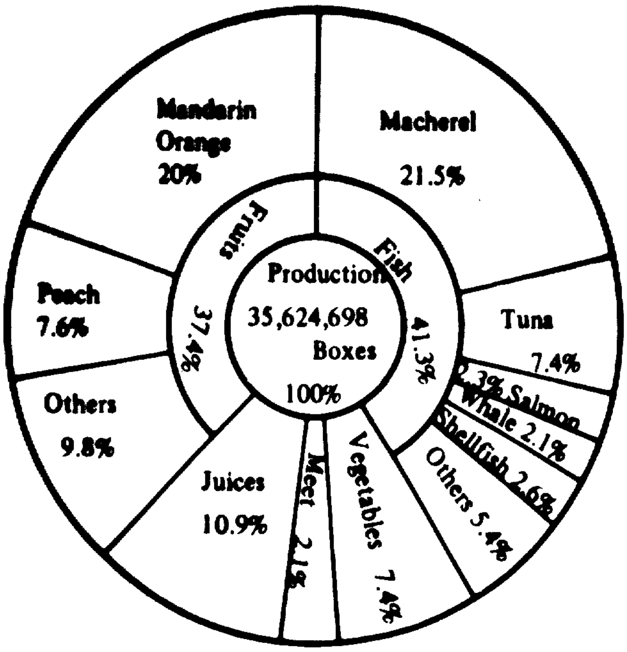


Fig. 3. Ratios of food preserved in tin cans

Source: J.C.A. (1968)

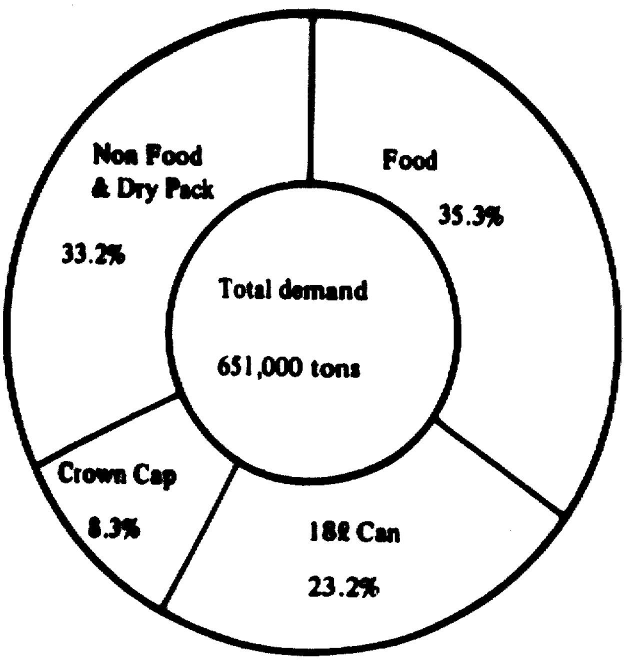
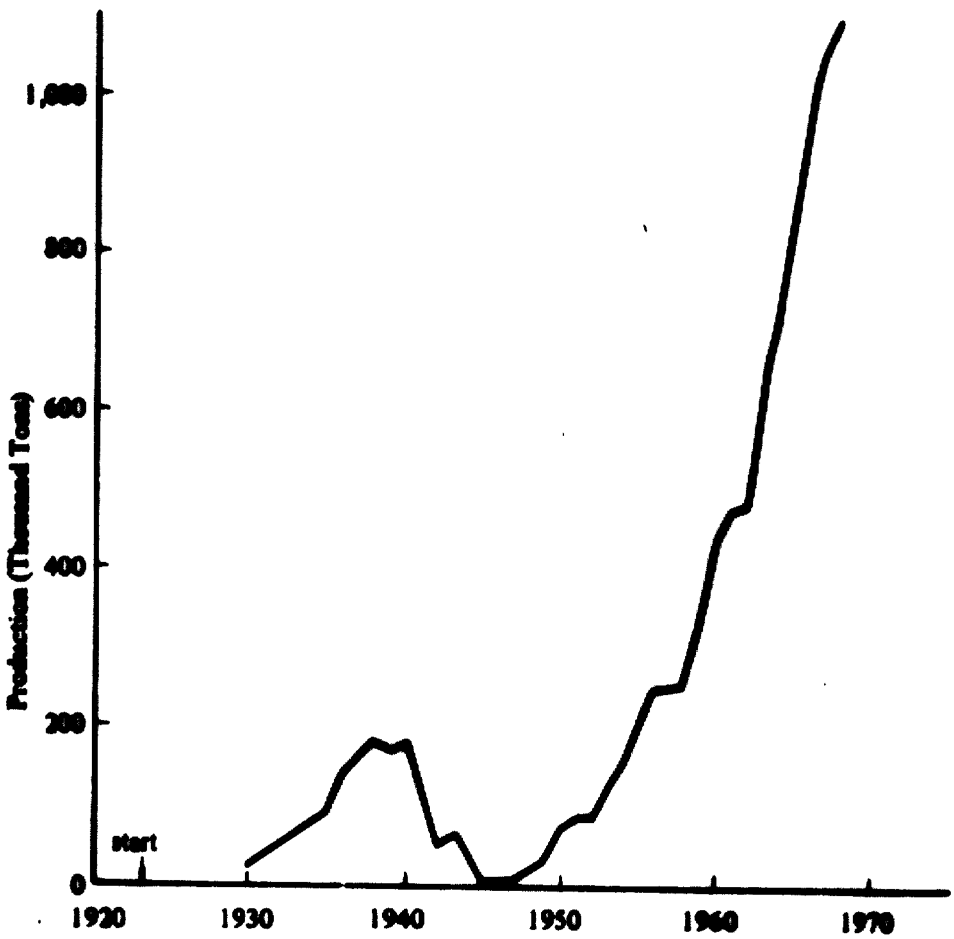


Fig. 2. Usage and ratio of containers
Source: J.I.S.F. (1968)



Source: J.I.S.F.

Fig. 1. Production of tin plate in Japan

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