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Manufacture of Soft-temper Blackplates in Kawatetsu Multipurpose Continuous Annealing Line (KM-CAL)

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Synopsis :
The multipurpose continuous annealing line developed by Kawasaki Steel Corporation (KM-CAL) has rapid cooling and overaging sections to additionally manufacture soft-temper tin mill blackplates which have so far been produced by the batch annealing process. Further, improvements such as in-furnace bridle rolls are incorporated in this continuous annealing line to permit rapid cooling without the deterioration of flatness even in extra-thin steel sheets. The conditions for the production of soft-temper tin mill blackplates by KM-CAL are: (1)use of low-carbon Al-killed CC slabs of 0.02 to 0.07%C and not more than 0.003%N, (2)hot mill coiling temperature of 620℃, (3)continuous annealing conditions: recrystallization temperature of 700℃, rapid cooling rate of 40 to 70℃/s and overaging at 400 to 450℃ for 60 sec, and (4)temper rolling with at low reduction of 0.8%. Commercial production was successfully carried out.

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Manufacture of Soft-temper Blackplates in Kawatetsu Multipurpose Continuous Annealing Line (KM-CAL)*

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1 Introduction

The tinplates used for the manufacture of beverage and food cans are specified by temper. The temper is represented by the value of Rockwell hardness (H_R30T) in JIS G3303, and classified in 6 steps, T1 to T6, from soft to hard tempers. In order to manufacture tinplates of different tempers, it was customary to adopt the batch annealing process for soft-temper tin mill backplates equal to or milder than T3, and the continuous annealing process for hard temper ones equal to or harder than T4. It has now become desirable, however, to apply the continuous annealing process to the production of soft temper balckplates which provides uniform properties through short-time annealing.

It has been reported[1] that soft-temper blackplates can be manufactured from rimmed steel by the continuous annealing process involving a high coiling temperature (to be abbreviated as CT hereinafter) after hot rolling followed by cold rolling, recrystallization annealing, rapid cooling and overaging. However, while the continuous annealing of rimmed steel, which contains a smaller amount of carbon in the rim layer at the edges of sheet width, provides low hardness, the hardness distribution in the cross-rolling direction becomes fairly non-uniform. On the other hand, if soft temper blackplate can be manufactured from continuous-cast Al-killed steel through the continuous annealing process, it is expected that the mechanical properties of the tinplate can be improved, as stated below:

(1) Owing to the uniform distribution of the chemical composition, the homogeneous distribution of the mechanical properties can be assured. Hence, the flatness is improved[2], eliminating the possibility of shearing in multi-color printing.
(2) Because of enhanced cleanliness and decrease of nonmetallic inclusions exposed at the sheet surface, the corrosion resistance of tinplate can be greatly improved[3].
(3) As the yield strength of continuous-annealed blackplate is increased, coating can be made through the roll coater system without causing coated sheet warp.
(4) Since the annealing time is markedly shortened, surface defects caused by the enrichment of carbon and manganese at the sheet surface during annealing can be prevented. Since silicon used as deoxidizing element deteriorates the corrosion resistance of tinplate, it is desirable to use Al-killed steel[4].

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However, there have scarcely been any reports on soft-temper blackplates manufactured from killed steel through continuous annealing, nor have there been examples of commercial production.

The authors examined the conditions for manufacturing soft-temper blackplates through the continuous annealing process from continuously cast Al-killed steel, and succeeded in realizing their manufacture on a commercial basis. The outline will be presented below.

2 Feasibility of Multipurpose Continuous Annealing Line for Manufacture of Soft-temper Blackplates

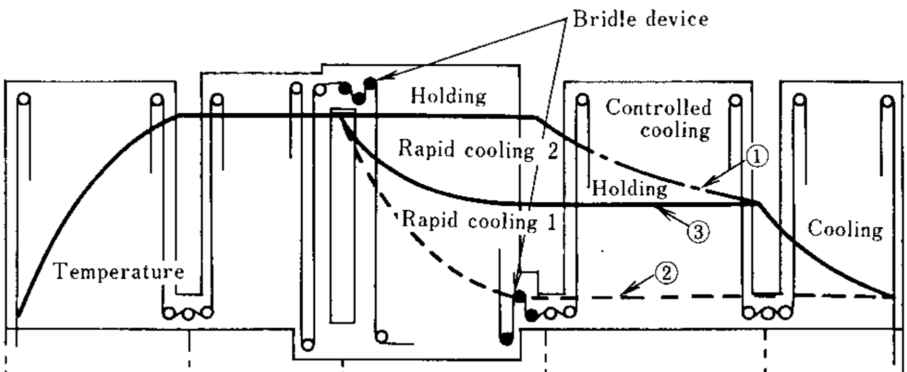
The Kawasaki Steel Multipurpose Continuous Annealing Line (KM-CAL) was installed and put to practical operation in July 1980[5]. As shown in **Fig. 1**, the KM-CAL is designed to include rapid cooling and overaging equipment, provide three kinds of heat cycle in one pass, and manufacture five types of product. As for tinplates, it was expected to manufacture not only hard temper tinplates which could be produced by the conventional CAL, but also soft temper tinplates.

When manufacturing soft-temper blackplates with the conventional CAL, the following problems arise: ① Owing to simple cooling, solute carbon hardens the sheet and ② a temperature difference is created because of uneven cooling in the transverse direction, deteriorating the flatness and the traveling in the furnace.

In designing the KM-CAL, the following countermeasures were taken against these problems.

(1) The soaking zone is to be held at a high temperature.
(2) The cooling zone is composed of three zones: at the 1st zone, rapid cooling is adopted so as to enhance the degree of supersaturation of solute carbon; at the 2nd zone, the temperature is held to provide overaging so that carbon is precipitated and the 3rd zone the steel strip is cooled to a temperature at which the strip is not oxidized when it comes in contact with the air.
(3) The temperature distribution in the transverse direction is monitored, and the cooling rate is controlled so as to ensure uniform cooling in the transverse direction.
(4) At the entry and exit of the 1st cooling zone, bridle rolls are installed so that the steel strip passes through the rapid cooling zone under a tension about 200 kgf lower than that in the other zones, as shown in **Fig. 2**.
(5) Roll heaters are provided so as to reduce the temperature difference between the steel sheet and the roll.

Through these measures, extra-thin steel strip such as tinplates could be subjected to rapid cooling without deteriorating the flatness.



	Type of steel	HS*	SS*	1st CS*	2nd CS*	3rd CS*
1	High temper tinplate Electrical steel	Heating	Soaking	Holding	Controlled cooling	Cooling
2	Dual phase steel	Heating	Soaking	Rapid cooling 1	—	—
3	Low temper tinplate Cold rolled sheets	Heating	Soaking	Rapid cooling 2	Holding	Cooling

*HS : Heating section, SS : Soaking section, CS : Cooling section

Fig. 1 Structure of the furnace and function of each section

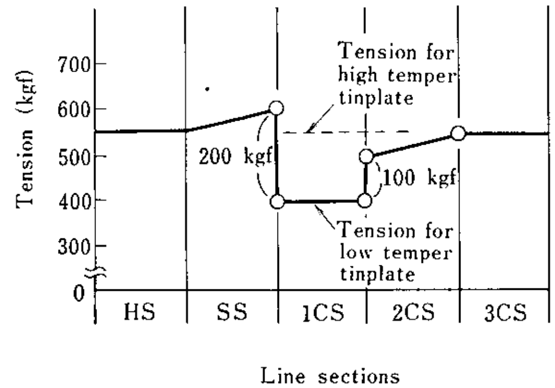


Fig. 2 Tension applied to thin gage (below 0.22 mm) in each section of hearth for low temper tinplate

3 Investigation of Continuous Annealing Condition

In order to find the optimum heat cycle for practical production, specimens of 0.3 × 60 × 300 (mm) were taken from a cold rolled steel sheet, which had the chemical composition shown in **Table 1** and was subjected to hot rolling under the conditions shown in **Table 1**. Cold reduction is 88 %. The simulation for continuous annealing was conducted in a direct resistance-heating furnace.

When determining the continuous annealing conditions favorable for extra-thin tinplate, easy annealing work must be considered first. For this reason, it was intended to keep the annealing temperature as low as possible.

The results are shown in **Fig. 3**. The heat cycle consists of two phases: recrystallization (soaking temperature T_r and soaking time t_r) and overaging (rapid cooling rate V_Q, overaging temperature T_o, and overaging time t_o). The recrystallization conditions determine the ferrite grain size and the carbide structure. Since the recrystallizing temperature T_r greatly depends upon the carbon content and the coiling temperature (CT) in hot rolling, T_r for the present purpose was set at 700°C at which even steel of lower carbon content recrystallizes adequately and which was lower than the A_1 temperature at which pearlite transformation begins. Next, in order to promote overaging effectively, it is important to increase the degree of supersaturation of the solute carbon. For this purpose, it is effective to increase the cooling rate and find the optimum overaging conditions thereafter. At first, V_Q was changed from 30 to 50 and to 100°C/s. However, as the effect of V_Q on hardness was small, V_Q was set to 40–70°C/s for the ease of operation. As for T_o, the hardness was high at 300°C and lowest at 400°C, while nearly unchanged in the range from 400 to 450°C. It was supposed that the progress of overaging was so retarded in case of 300°C that the hardness was enhanced. In examining t_o with T_o fixed at 450°C, it was found that the desired hardness was obtained by keeping t_o at 60 s or longer. Hence, in the subsequent experiments, the heat cycle described in the above was adopted with V_Q and t_o fixed at 50°C/s and 60 s, respectively.

Table 1 Chemical composition of CC Al-killed steel and hot rolling conditions (wt%)

Steel	C	Si	Mn	P	S	Al	N_{Total}	N as AlN
D 1	0.035	0.018	0.27	0.017	0.011	0.049	0.002 9	0.002 0

FT : 835°C
CT : 520°C
Thickness of hot coil : 2.6 mm

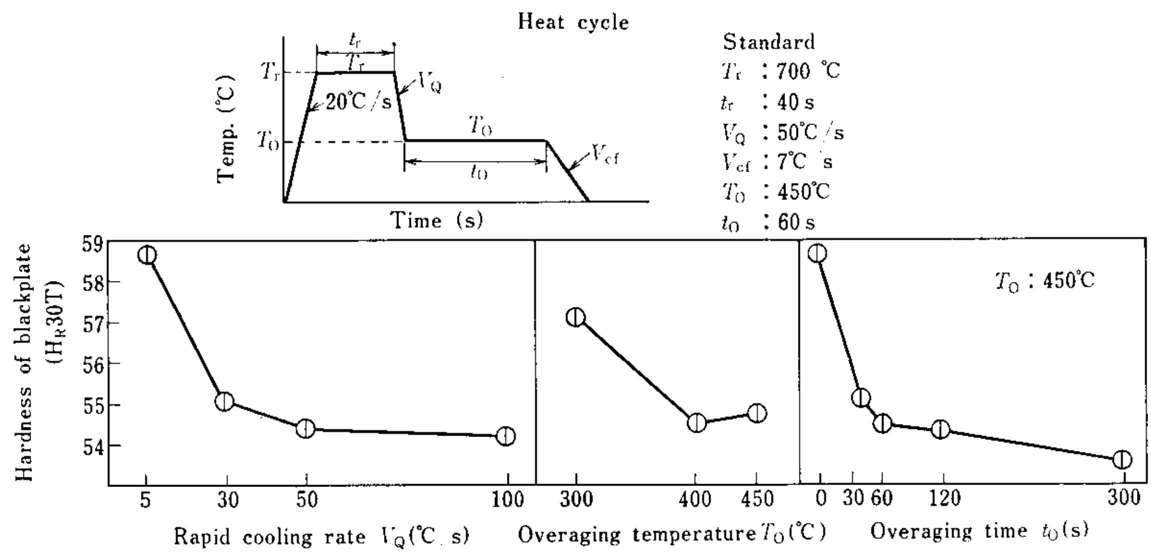


Fig. 3 Effects of heat cycle on hardness of blackplate

4 Experiment of Temper Rolling Conditions

It is rather difficult to obtain non-aging steel sheets from low carbon steel even through rapid cooling and overaging by the KM-CAL. Moreover, tinplates are subjected to the reflow treatment (water quenching starting at 350°C). In this case, the solute carbon and nitrogen are segregated at the dislocations induced by the temper rolling, thus increasing the strain age hardening. It is important, therefore, to select an appropriate temper rolling reduction when producing soft-temper blackplates.

The hot rolled steel strip shown in **Table 1** was pickled and cold rolled to 0.3 mm thick. The cold rolled strip was annealed through the heat cycle described in the above by the KM-CAL, and specimens were taken. The specimens were rolled with a laboratory rolling mill at various reduction rates and the hardness was measured. Subsequently, tinning and reflow treatment were carried out in the laboratory, and the hardness was measured again. The results are shown in **Fig. 4**. Note that the hardness increases steadily with the reduction ratio. In the subsequent experiments, the reduction ratio was set at 0.8% in consideration of the plate surface roughness and flattening.

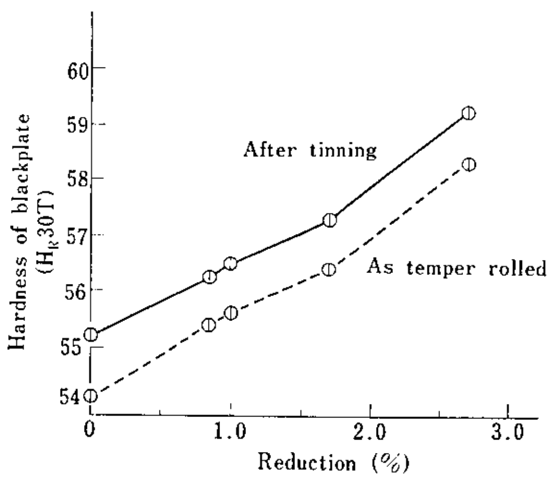


Fig. 4 Effect of temper rolling reduction on hardness in tinplate and blackplate

5 Selection of Materials Suited for KM-CAL

5.1 Experimental Method

The experiment was conducted using a 2.6 mm thick sheet with its chemical composition and hot rolling conditions shown in **Table 2**. The higher the CT, the larger the ferrite grains; and at 640°C or higher, carbides become coarser, deteriorating the tinplate's corrosion resistance when emerging on the surface of blackplates[6]. For this reason, CT was held at 620°C maximum at which the corrosion resistance could be held at an excellent level previously attained. In steels A, C, D, F and G, the total nitrogen content (N_{Total}) was fixed at 0.0025% approximately, while the carbon content was varied in five levels, in order to check the effects of C content on the mechanical properties. In steel B, the nitrogen content was increased to 0.004% with the carbon content held at the same level as steel A, and in steel E, the nitrogen content was increased to 0.004% while the carbon content was held at the same level as steel D. Steels B and E were used for studying the effects of the nitrogen content on the mechanical properties. The finishing temperature of hot rolling was almost the

Table 2 Hot rolling conditions and chemical composition of annealed samples

Symbols		Hot rolling conditions		Chemical composition (wt%)								
		Finishing temperature (℃)	Coiling temperature (℃)	C	Si	Mn	P	S	Al	N_{Total}	N as AlN	N_{Total}−N as AlN
A-1	○	860	540	0.008	0.016	0.25	0.017	0.008	0.024	0.002 3	0.001 2	0.001 1
A-2	◇	860	620	0.008	0.017	0.25	0.017	0.008	0.025	0.002 1	0.001 2	0.000 9
B-1	-○-	855	535	0.007	0.018	0.27	0.016	0.012	0.031	0.004 1	0.001 1	0.003 0
C-1	⊙	845	540	0.024	0.012	0.26	0.019	0.014	0.047	0.002 3	0.001 3	0.001 0
C-2	◈	850	625	0.021	0.011	0.26	0.018	0.012	0.047	0.002 8	0.002 0	0.000 8
D-1	⦶	835	520	0.035	0.018	0.27	0.017	0.011	0.049	0.002 9	0.002 0	0.000 9
D-2	◇	835	625	0.034	0.017	0.27	0.016	0.010	0.047	0.002 9	0.002 7	0.000 2
E-1	-⦶-	860	540	0.042	0.022	0.27	0.018	0.012	0.044	0.004 4	0.002 0	0.002 4
F-1	◑	837	515	0.059	0.013	0.26	0.014	0.012	0.050	0.002 0	0.001 5	0.000 5
F-2	◆	830	625	0.056	0.014	0.26	0.012	0.011	0.050	0.002 0	0.001 9	0.000 1
G-1	●	850	540	0.073	0.016	0.26	0.017	0.014	0.042	0.002 3	0.001 5	0.000 8
G-2	◆	850	615	0.068	0.016	0.26	0.017	0.013	0.042	0.002 4	0.002 0	0.000 4

same for each steel, and the CT was set at lower (540°C or so) and medium temperatures (620°C or so).

The hot rolled steel strips were pickled, cold rolled to 0.3 mm thickness, annealed in the KM-CAL through the heat cycle mentioned above, and temper-rolled with a two-stand temper mill at a reduction ratio of 0.8 %. The blackplates were tinned to coating weight 5.6 g/m² (coating weight index #25) on the Halogen type electrotinning line, and then subjected to the reflow treatment. The test specimens were taken out of these tinplates to examine the hardness, tensile strength and chemical composition. For steels A, C and G, specimens were taken at the ends of continuous annealing, temper-rolling and tinning-reflowing, to check the changes in hardness in each process. In order to determine the overall effects of residual solute components on the mechanical properties, the aging index has generally been used. In the present experiment, N content in AlN were determined by the bromine ester method, and the difference between N_{Total} and N content was regarded as the content of solute nitrogen. The effect of solute nitrogen contents on materials which had nearly identical carbon contents and carbide dispersions was studied.

5.2 Effects of C and N Contents and CT on Mechanical Properties of Tinplates[7)]

The effects of carbon and solute nitrogen contents on the mechanical properties of tinplates are shown in **Fig. 5** for different coiling temperatures and nitrogen contents. The yield strength was high in every steel, and showed nearly the same tendency as the hardness with respect to the relationship to the manufacturing conditions. The following description concerns the hardness.

(1) Effect of C content
The hardness was minimal at 0.02–0.07 % C content, increasing as the C content increased or decreased. The highest hardness was found in steel A, which included the smallest C amount.

(2) Effect of N content
The hardness decreased linearly with a decrease of the solute N content.

(3) Effect of coiling temperature
Steels hot rolled at medium CT presented lower hardness than those at lower CT, irrespective of carbon contents. When comparing two steels; D-1 and E-1, both having nearly the same carbon contents, E-1 contained 14 ppm more solute nitrogen than D-1, with a hardness about 4 higher.

5.3 Effects of C Content and Coiling Temperature on Work Hardening and Strain Age Hardening

The effects of C content and coiling temperature on the hardness after each processing of continuous annealing, temper-rolling and tinning-reflowing were examined in steels A, C and G. The results are shown in **Fig. 6**.

(1) Changes in hardness
The hardness after continuous annealing was affected most noticeably by the CT. The hardness of steels hot rolled at medium CT was about 5 lower on an average than that of steels at lower CT. The work hardening after temper rolling presented a peculiar phenomenon. That is, while steel A containing the least C amount was hardened markedly irrespective of CT, steels C-1 and G-1 containing more carbon tended to become milder at lower CT. The strain age hardening

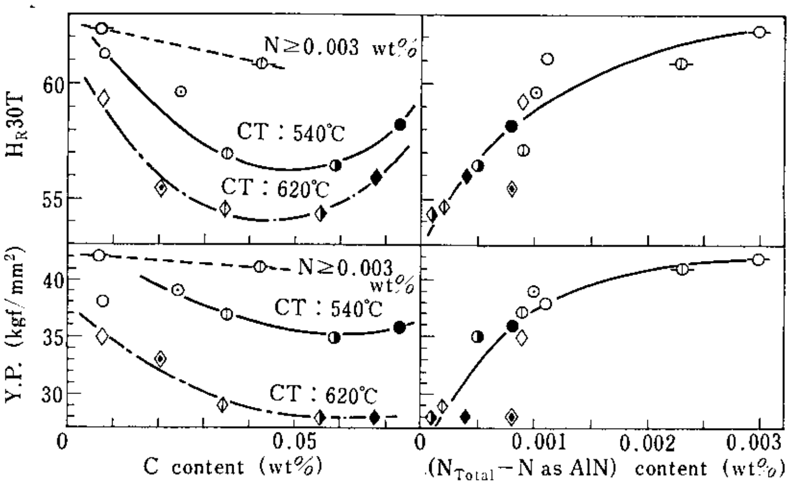


Fig. 5 Effect of carbon content and (N_{Total} − N as AlN) content on mechanical properties of tinplate after tinning

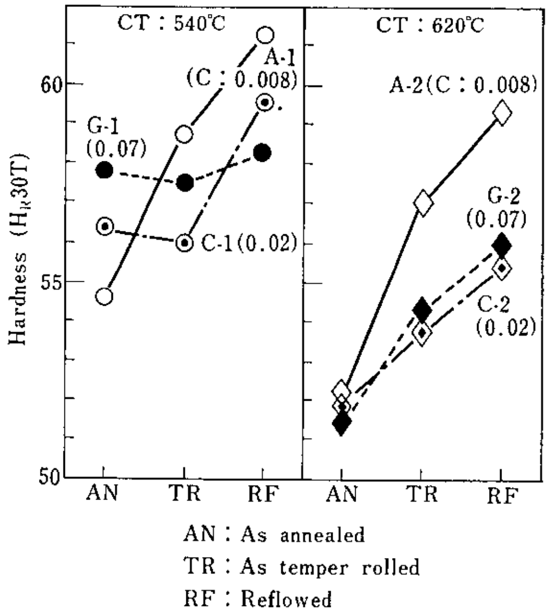


Fig. 6 Effect of carbon content and coiling temperature on hardness change during processing

through tinning-reflowing was as small as about 0.5 in steel G-1 which contained more carbon and was hot rolled at lower CT, but it largely increased in other steels. From the continuous annealing to tinning-reflowing, the hardness increased largely in steels containing lesser amount of carbon. The hardness of tinplates was lower in steels containing more carbon and hot rolled at lower CT, in contrast to the tendency of the hardness following the continuous annealing.

(2) Changes in microstructure

The microstructures of specimens taken after continuous annealing are shown in **Photo 1**. The crystal grain size was greater in steels containing less carbon. For steels having nearly the same amount of carbon, the grain size was coarser in steels hot rolled at medium CT than in those at lower CT. On the other hand, in steels, hot rolled at lower CT, fine carbide particles were found only rarely in steels containing less carbon, while densely distributed in carbon-rich steels. In steels

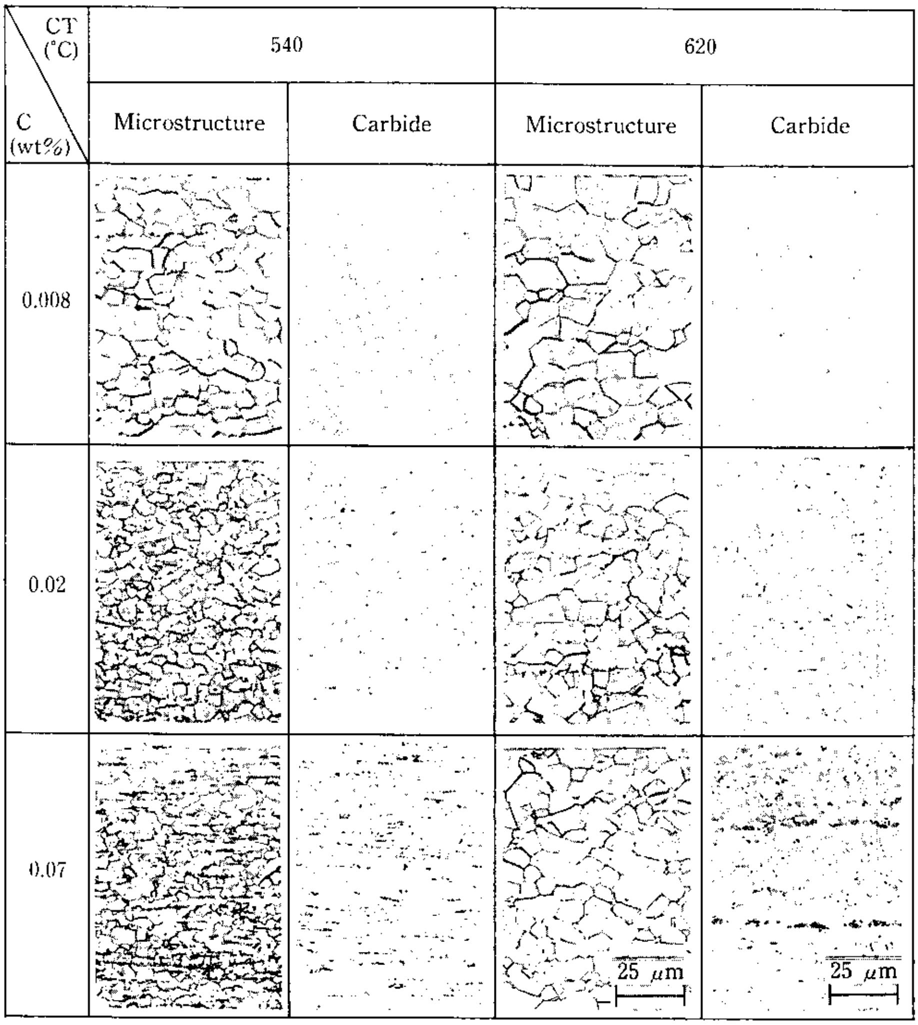


Photo 1 Optical micrographs of annealed tinplates

hot rolled at medium CT, carbide particles were coarser and distributed more sparsely than in those at lower CT.

5.4 Appropriate Materials Requirements[8)]

The results obtained through these experiments may be summarized as follows.

(1) Grain size and carbon precipitation
The hardness after continuous annealing depended greatly on the grain size, turning lower in steels hot rolled at medium CT and having coarser grains. When steels were treated at the same CT, the increase in the hardness from continuous annealing to tinning-reflowing was related to the grain size and the carbide distribution, becoming smaller in steels having finer crystal grains and denser distribution of fine carbide particles, and contrarily, the increase was larger in steels having coarser crystal grains and loose distribution of fine carbide particles. Generally speaking, in steels manufactured through batch annealing, the grain size steadily increases and the hardness becomes lower, if the C content is less. However, in steels made by continuous annealing, high hardness was obtained despite the coarser grain, if the C content was less than 0.02%. The phenomenon may be interpreted in the following way. When steels having lower C content are overaged for a short time in the continuous annealing process, their hardness decrease as the ferrite grains turn coarser. In addition to this, since the C content is too low, fine carbide particles which serve as precipitation sites of solute carbon turn sparse, making grain boundaries more widely spaced. This means that the diffusion distance required for the carbide precipitation is extended. Consequently, the precipitation of carbon after overaging is delayed to augment the age hardening at the time of tinning and increase the hardness. It is important, therefore, for manufacturing soft temper blackplates to increase the C content to such an extent that fine carbide particles exist adequately dense even if the grain size becomes smaller to some extent.

(2) Precipitation of AlN
The presence of solute nitrogen promotes solute hardening. In the batch annealing, nitrogen precipitates as AlN without leaving solute nitrogen. In the continuous annealing process, however, nitrogen does not precipitate fully as AlN, and a certain amount of solute nitrogen persists because of short annealing time. It is essential, therefore, to reduce the solute nitrogen before annealing. For this purpose, it seems effective to keep the nitrogen content in slab to 0.003% or less and to promote the precipitation of AlN during hot rolling by coiling at medium temperature so as to prevent carbide particles from coarsening. Though the ferrite grains grow and the carbide particles become coarser to some extent at the medium CT, the hardness is lower than that in steels hot rolled at lower CT. This is attributed to the fact that hardening by sparse distribution of carbide particles is overcome by the greater effect of increased grain size and AlN precipitation.

6 Manufacture of T_4–T_2 Tin Mill Blackplates

Since blackplates of different temper require different manufacturing conditions, the process control becomes complicated, failing to achieve high production efficiency. It was attempted, therefore, on the basis of the above-mentioned findings, to manufacture T_4–T_2 blackplates from Al-killed steels of identical composition with their hot rolling and annealing conditions changed.

For the present purpose, continuously cast slabs of low-carbon Al-killed steel of 0.055% C, 0.26% Mn and 0.018% Al were hot rolled to a thickness of 2.6 mm at various finishing temperatures and coiled at a medium temperature of 620°C. The strip pickled was cold rolled to a thickness of 0.3 mm, and annealed in the KM-CAL through a simple heat cycle practicable in the conventional CALs and a rapid cooling overaging cycle. After temper rolling at a low reduction of 0.8%,

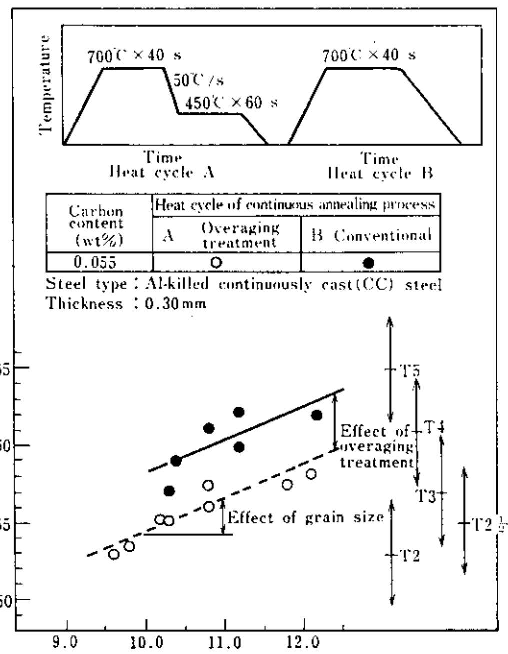


Fig. 7 Effect of overaging treatment, carbon content and grain size number (G.S. No.) on hardness of tinplate

the strip was subjected to tinning and reflowing, and the changes in hardness were examined. The results are shown in **Fig. 7**.

From the steels annealed using the simple heat cycle, T_4 tinplates of about 61 hardness were obtained. On the other hand, when steels were rapidly cooled at a rate of 50°C/s and overaged for 60 sec. at 450°C, the hardness was about 3.5 lower than the preceding one, thereby turning into T_3 tinplates. If the grain size is increased further, it may be possible to manufacture T_2 tinplates.

7 Production on a Commercial Base

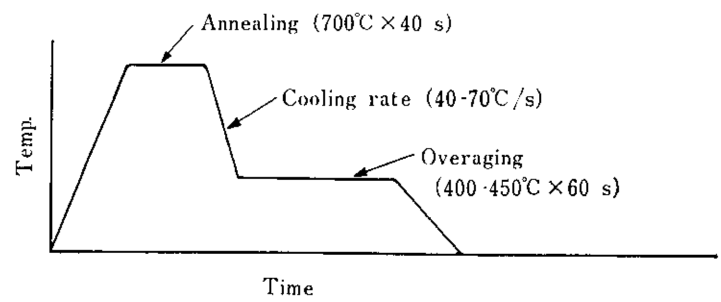
The optimum conditions for producing soft-temper blackplates by the KM-CAL are summarized in **Table 3**. For obtaining soft-temper blackplates, it is important to make ferrite grains coarser and to reduce the contents of solute carbon and nitrogen. The conditions of continuous annealing should be such that the recrystallization temperature is set higher so as to promote the grain growth, with a heat cycle adopted so as to facilitate the precipitation of carbide in the rapid cooling-overaging zone. The conditions of steel should be such that it has dense distribution of fine carbide particles serving as the precipitation sites of solute carbon, with lesser amount of solute nitrogen and with crystal grains made coarser.

In order to reduce the nitrogen content to 0.003 % or less, it is essential to prevent nitrogen absorption from the atmosphere during Al deoxidation in the stage of steelmaking. This is effectively done by isolating molten steel in ladle from the air and add Al-wire while stirring with inert gas blown into the bottom of the ladle.

Through these improvements, it has become possible to manufacture soft-temper tinplates of thickness as small as 0.20 mm. Since the start of the KM-CAL operation in July 1980, not only hard-temper, but also soft-temper blackplates such as T_3–T_2 have been produced on an industrial scale.

Fig. 8 shows the fluctuations of hardness in the commercially produced T_3 tinplates made from ingot-cast and continuously cast materials, through the batch annealing process and the KM-CAL. The tinplate manufactured from the continuously cast steel strip through the KM-CAL showed minimum fluctuation in hardness. When compared with the

Table 3 Conditions suitable for producing soft temper tinplate in KM-CAL

Material steel	Steel type : C.C. low carbon Al-killed steel C : 0.02–0.07(wt %) $N_{Total} \leq 0.003$(wt%) N_{Total} − N as AlN ≤ 0.001(wt%)
Hot rolling	Coiling temp. : 620°C
Heating cycle	
Temper rolling	Rolling reduction : 0.8(%)

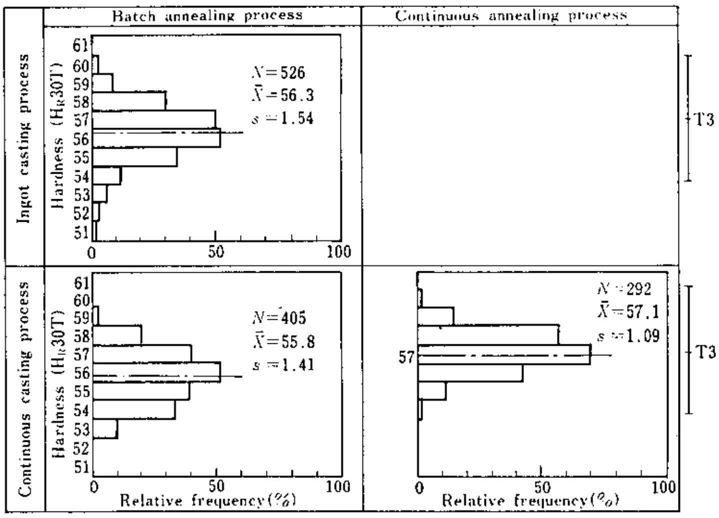


Fig. 8 Effect of slab production process and annealing process on the hardness distribution of low temper tinplate

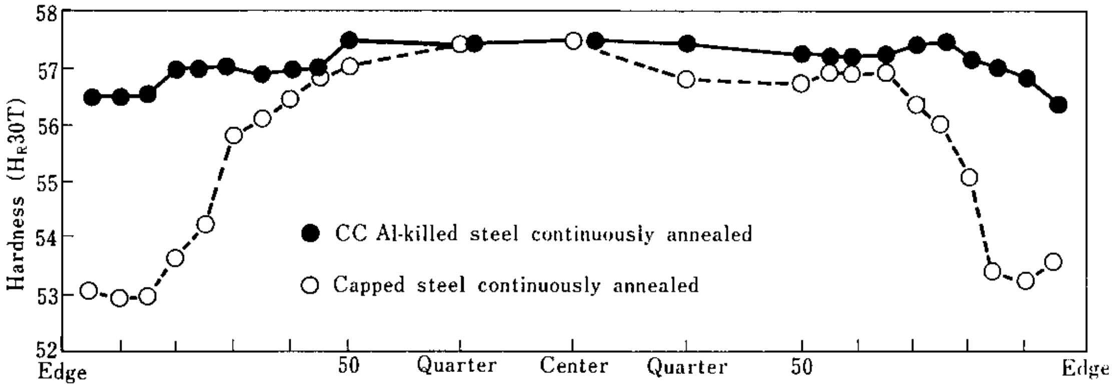


Fig. 9 Distribution of tinplate hardness in traverse direction

blackplates made from capped steel through continuous annealing, those made from continuously cast Al-killed steel displayed marked improvement in the distribution of hardness in the transverse direction as shown in **Fig. 9**.

Moreover, the soft-temper tinplates produced from Al-killed steel through continuous casting–continuous annealing demonstrated a yield strength high enough to forestall any cambering during roll coating.

8 Conclusion

The Kawasaki Steel Multipurpose Continuous Annealing Line (KM-CAL) is provided with rapid cooling and overaging sections to produce soft-temper blackplates which have so far been made by batch annealing. Further, various improvements are incorporated in the KM-CAL to permit rapid cooling without deteriorating the flatness even in extra-thin steel sheets. In the present series of experiments, various conditions for manufacturing soft-temper tin mill blackplates in the KM-CAL, particularly those affecting the hardness such as steelmaking, hot rolling, annealing and temper-rolling conditions were examined. Consequently, conditions for manufacturing the said blackplates from continuously cast Al-killed steel slabs were established for a commercial production. The conditions for producing T_3–T_2 soft-temper blackplates with uniformly distributed mechanical properties are summarized below.

(1) Low-carbon Al-killed CC slabs containing 0.02–0.07% C and 0.003% or less N are to be used as materials.
(2) The coiling temperature after hot rolling is to be set at a medium level of 620°C or there about.
(3) The heat cycle of continuous annealing will involve recrystallization at 700°C or thereabout, rapid cooling at 40°–70°C/s and overaging at 400°–450°C for 60s
(4) Temper rolling is to be performed at a reduction ratio as low as 0.8%.

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