A Study on the Annealing Characteristics of BAF for Cold Rolled Steel Strip

Soon Kyung Kim*, Moon Kyung Kim and Eon Chan Jeon*****

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The cold spot temperature control system for BAF (Batch Annealing Furnace) has been established in order to reduce energy consumption to improve productivity and to stabilize the properties of products. We improved material quality, increased output, and decreased the annealing cost and homogeneous distribution of cold spot temperature in BAF. The introduction of H_2 instead of N_2 as atmospheric gas, combined with high convection in BAF, has resulted in a considerable increase in furnace efficiency and material quality. By the low density, high diffusibility, and reducing character of H_2, a better heat transfer resulting in uniform material temperature and improved coil surface can be achieved. The results in this study are as follows; Heating time is reduced to one half by increasing the inflow rate of atmospheric gas and changing of atmospheric gas component from HNx(H_2: 5%, N_2: 95%) to Ax(H_2: 75%, N_2: 25%) gas. The annealing cycle time is also reduced to 2.7 times. In the case of HNx BAF the cold spot moved to the center after 32 hours of heating, while in the case of H_2 BAF it moved from the one-third position of the B coil inside to the center just after 12 hours of heating, resulting from a heat transfer increase to the radius direction. The temperature in this part is higher than any other parts when cooling. Soaking time at batch annealing cycle is decided by input coil width, and the time for quality homogenization of 1219 mm width coil must be longer by 2.0 hours than that of 914 mm width coil with the same coil weight at H_2 BAF, however, it is necessary to make 2.5 hours longer at HNx BAF.

Key Words: Cold Spot, Batch Annealing Furnace, Atmospheric Gas, Annealing Cycle, Homogenization, Hot Spot

Nomenclature

A_1 : Inlet area of the diffuser
A_2 : Outlet area of the diffuser
A : Heat transfer area of coils
C_P : Specific of the atmospheric gas
D : Diameter of the gas flow
h : Heat transfer coefficient
k : Thermal conductivity of gas
Pr : Prandtle number
P_1 : Inlet pressure of the diffuser
P_2 : Outlet pressure of the diffuser
Q : Heat transference
Re : Reynolds number
Ts : Outer surface temperature of the coils
Tg : Atmospheric gas temperature
V : Atmospheric gas velocity

Greek symbols

ρ : Density of the atmospheric gas
μ : Viscosity of the atmospheric gas
η : Pressure efficiency of the diffuser

* Automotive Engineering Dept., Dong Eui Technical Junior College
** Mechanical Design Dept., Chang Won Junior College
*** Mechanical Engineering Dept., Dong-A University

1. Introduction

The annealing process plays an important role in recrystallizing the deformed micro- structure by rolling and ensuring product quality of adequate workability.

There are two types of annealing equipment which conduct heat treatment of steel coils such as the Continuous Annealing Line(CAL) and the Batch Annealing Furnace(BAF). Till now the BAF which considers the mediocrities, economics, and operations has been widely used in spite of the fact that most newly-constructed annealing equipment is inclined to adopt the CAL method except in jobshop production such as nonferrous, special steel (Mizikar, 1972 ; Tajima, 1977).

Various research materials show that the annealing gas provides greatly improved effects according to the contents of hydrogen of good heat transfer and reductionablity. However there are few research results concerning the effects of the variation of components of atmospheric gas and flow rate on heating time in actual BAF. The difference between furnace temperature and cycle control time affect the annealing process time. Accordingly, we inspected the effects of the variation of flow rate and the maximum temperature change in the furnace on heating and cooling time in HNx BAF (Rovito, 1989; Harvar, 1987). Soaking time according to width, relation between thermocouples, which are controlled generally, and cold spot are compared with the H_2 BAF and the HNx BAF to the total annealing cycle. We experimented using BAF which is produced in order to establish an annealing cycle which is most important for increasing productivity and quality.

2. Theoretical Background

Using BAF annealing which is adequate for jobshop production, heat is transferred from burner to coil through inner cover, and 70-80% of the total heat is transferred by convection even if conduction and radiation are also involved (Rao, 1983). Convective heat transfer is caused by the atmospheric gas (Perrin, 1988) which flows compulsively by use of a base fan. Figure 1 illustrates the heat transfer process from inner cover to coil. it was compares the heat transfer coefficient of hydrogen with that of nitrogen.

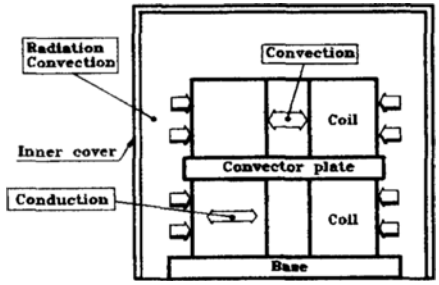


Fig. 1 Schematic diagram of heat transfer.

Table 1 Physical properties of hydrogen and nitrogen (at 250K).

Items	H_2(a)	N_2(b)	a/b
Thermal conductivity (W/m.k)	0.157	0.022	7
Viscosity (Pa/s)	7.89×10^{-6}	15.49×10^{-6}	1/2
Density ($kg.s^2/m^4$)	0.097	1.348	1/14

Thermo-physical properties of hydrogen and nitrogen gas are listed in Table 1. The heat transfer coefficient may differ according to the plate surface roughness of coil, tension after electrolytic cleaning, and the characteristics of the furnace. The convective heat transfer coefficient, heat transfer rate, and different efficiency are given by

$$h\cdot\frac{D}{k}=0.023Re^{0.8}\ Pr^{0.33} \tag{1}$$

$$Q=h\cdot A(T_g-T_s) \tag{2}$$

$$\eta=\frac{P_1-P_2}{0.5\cdot V^2\cdot\rho\{1-(A_1/A_2)^2\}} \tag{3}$$

where

$$Re=\frac{V\cdot D\cdot\rho}{\mu},\quad Pr=\frac{C_p\cdot\mu}{k}$$

In the above formula (1), the heat transfer coefficient h is depends on Reynolds number and Prandtle number. The Reynolds number is proportional to gas velocity and diameter of flow. Accordingly total heat transfer to the coil is greatly affected by the impeller diameter of base

Table 2 Chemical composition of specimen (wt. %).

Material	C	Si	Mn	Al	Cu
SAE 1008	0.05	0.009	0.25	0.010	0.010

Table 3 Mechanical properties of specimen.

Material	Tensile strength (N/mm²)	Yield strength (N/mm²)	Hardness (H_{RB})	Elongation (%)
SAE 1008	710.000	640.80	85.90	4.20

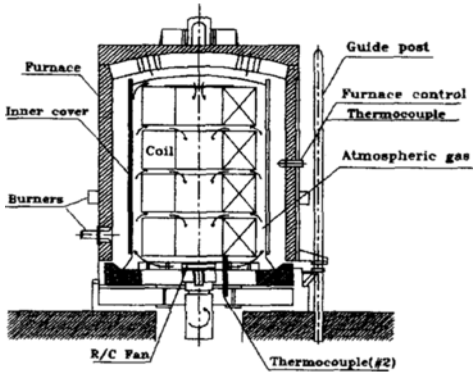


Fig. 2 Schematic diagram of HNx BAF.

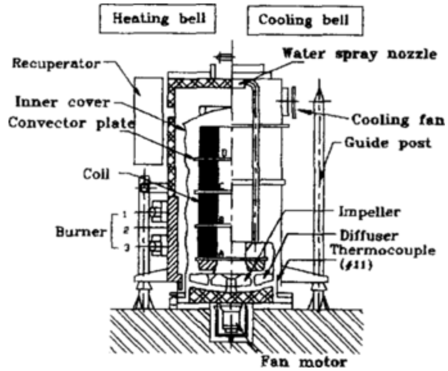


Fig. 3 Schematic diagram of H_2 BAF.

fan which controls gas velocity and power. The pressure efficiency of the diffuser can be obtained in from (3) and determined by the velocity of the atmospheric gas.

3. Experimental Equipment

3.1 Materials

In this experiment, SAE 1008 was employed as the test material because it is widely used in cold rolling process. Table 2 and Table 3 shows the chemical components and the mechanical properties of the material (specimen) respectively. The specimen is in the form of coil, which is treated with cold rolling and electrolytic cleaning. The thickness is 1.0 mm and two sizes of coil width of 914 (narrow) mm, 1219 (wide) mm are used.

3.2 Experimental equipment

The BAF annealing was performed by heat transfer, By using convector plates between the coils the atmospheric gas is supplied through the diffuser from the fan at the base. Atmospheric gas flows into the center of coil through the convector plate as shown in Fig. 2. Because it is impossible to control the uniform temperature of each coil constantly, the cold spot is found out through the test and decided through the heat-treating cycle by the lowest temperature. (Zecca, 1977)

In a furnace using HNx gas the thermocouple to control temperature is installed in the base which is easy to install. When using Ax gas as indicated in Fig. 3 the temperature of the atmospheric gas is controlled by the thermocouple installed between the inner cover and the coil. The temperature of the cold spot is controlled using measured temperature. To install the thermocouple (#11) for measuring the temperature of the atmospheric gas is a standard procedure in the heat-treating cycle. The temperature of the furnace itself is controlled by the thermocouple installed in the furnace.

4. Experimental Method

As in BAF annealing the heating and cooling time vary according to the components of the atmospheric gas and the input gas amount as shown in Table 4.

The heating and cooling times of HNx and Ax gas are measured as indicated in Fig. 4. There is a mutual relationship between the cold spot and the thermocouple for the annealing cycle control.

Table 4 Gas flow rate at HNx BAF.

Purging	Total gas flow rate(m^3/h)		
	8	9	10
0-400	3	6	9
401-600	3	4	5
601-Soaking	3	10	20
Cooling	5	10	20

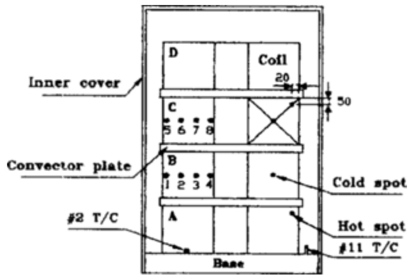


Fig. 4 Thermocouple position of each coil (coil weight: 20 ton).

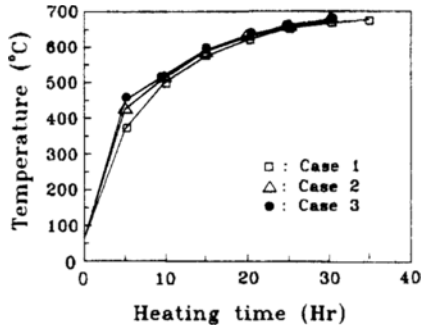


Fig. 5 Relation between heating time and temperature at the HNx BAF.

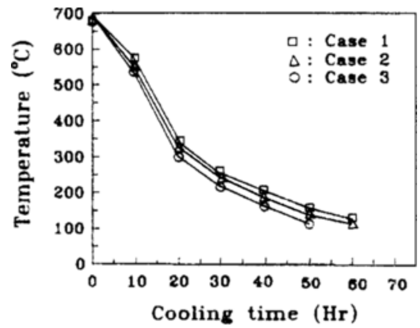


Fig. 6 Relation between cooling time and temperature at the HNx BAF.

So, it is very important to find the cold spot of the BAF. It is possible to decrease the production cost by heat-treating with adequate temperature and to acquire good mechanical property of steel sheet by application of adequate soaking time according to the coil width. The thermocouple position is shown in Fig. 4, and the cold spot of the coil and the variation of the annealing cycle temperature were investigated. While heating the cold spot and cooling the hot spot, various effects such as, homogeneous mechanical properties on the sheet steel are very important. It was checked out from the temperature variation of the two spots.

5. Experimental Results and Discussion

5.1 Heat transfer variation with input gas flow rate

In the case of the HNx BAF, the heating time decreases as the flow rate of the atmospheric gas increases as indicated in Fig. 5.

The heat transfer coefficient in Eq. (1) for a fixed diffuser diameter D is more affected by the thermal conductivity than by the atmospheric gas velocity(v). As can be seen in Eqs. (1) and (2), if the coil section area is constant, the heat transfer coefficient is proportional to the flow rate and component of input gas. As for cases 2 and 3 with more input gas, it took 30 hours to reach 700℃, but in case 1 with less input gas, it took approximately 34 hours. When cooling, like heating, cooling time varies according to the input gas flow rate as shown in Fig. 6. Consequently, as shown in Figs. 5 and 6 if the component of atmospheric gas is the same, elevation of the coil temperature does not change much with the variation of atmosphere gas flow rate.

5.2 The control temperature of annealing cycle and the variation of the cold spot

Figure 7 shows that total annealing time when using HNx as the atmospheric gas, it takes 48 hours for cold spot to reach 680℃, and it takes about 135 hours to cool down 80 ℃. But Fig. 8 shows that when using the Ax gas, total annealing

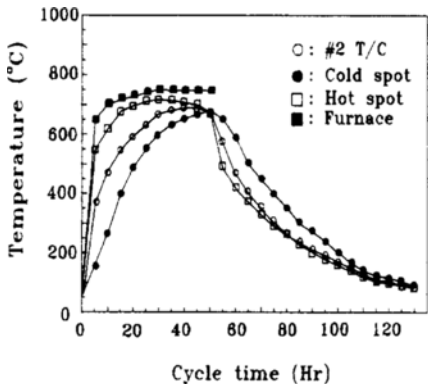


Fig. 7 Relationship bwtween cycle tiem and temperature at the HNx BAF.

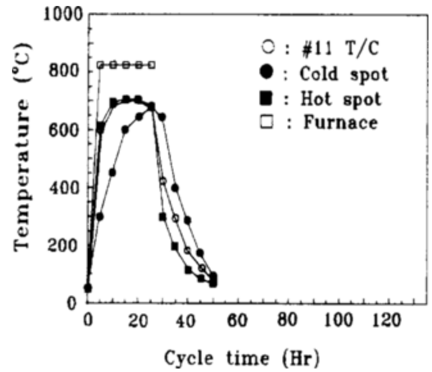


Fig. 8 Relationship bwtween cycle tiem and temperature at the H_2 BAF.

time which includes heating, soaking and cooling decreases.

In the case of Ax gas, as indicated in Table 1, the heat transfer coefficient of hydrogen is seven times higher than that of nitrogen, so the heating time and the cooling time are shorter than that of HNx gas. As shown in Eq. (3), the high efficiency annealing furnace which uses the Ax gas has wide area(A), high pressure(p), and low density(ρ). So, the high diffusion efficiency reduces the heating time.

The thermocouple is inserted to the mid part of the coil because it is assumed the cold spot of the Fig. 7 and Fig. 8 is in the mid point of the coil. Fig. 7 and Fig. 8 show the relationship between the cold spot, hot spot, and thermocouple temperature for annealing cycle controlling(Sterling, 1986).

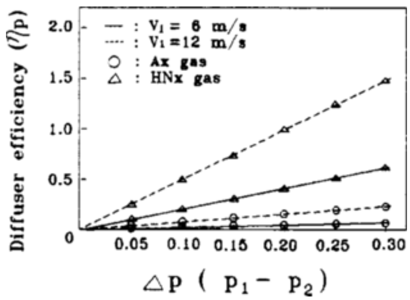


Fig. 9 Relationship bwtween pressuredifference and diffuser efficiency.

The mid part of coil B has the lowest increasing rate of temperature during heating. The outer part of coil C has the highest increasing rate of temperature. The #2 thermocouple temperature for the annealing cycle control is between the hot spot and the cold spot at Fig. 7 (Ravito, 1991). The #11 thermocouple at Ax gas reads the temperature of the atmospheric gas and it controles the annealing cycle at Fig. 8. This data results from the temperature variation among the inner part, the mid part, and the outer part of the coil at Fig. 7 and Fig. 8. Because the Ax gas has more heat transfer effect to the radial direction than that of the HNx gas, the annealing cycle at the Ax gas becomes short.

The temperature at the cold spot during the cooling process increases for about 2 hours and then decreases slowly. The temperature increase after the heating process is due to the fact that it is lower than that of the outer part.

If the atmospheric gas velocity supplied by the recirculation fan is constant, the diffuser efficiency(using Eq. (3)) is proportional to the pressure difference of entrance and exit of the diffuser as shown in Fig. 9. Diffuser efficiency of Ax gas compared with HNx gas in the $\triangle$p(0.30) is approximately 6 times higher. Therefore, Fig. 7 and Fig. 8 show that BAF using sparse Ax gas has a fast temperature increase due to the efficiency of the diffuser and Ax gas itself.

Temperature increase of the coil as shown in Fig. 5 and Fig. 6 has few differences according to the change of atmospheric gas flow rate. But by the increase of the H_2 component of atmospheric gas as shown in Fig. 7 and Fig. 8, heat rate of

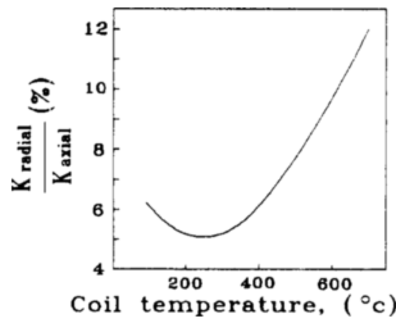


Fig. 10 Relationship bwtween coil temperature and heat transfer ratio(k).

BAF using H_2 as Ax gas (which has a high heat transfer ratio to the direction of the radius) is 2 times faster than that of N_2. Accordingly, it can be seen that heat rate in the BAF is affected by the heat transfer ratio to the direction of radius rather than to the direction of axis.

Figure 10 shows the heat transfer in the direction of axis and the direction of radius of the coil at HNx BAF. This means that the lowest heat transfer ratio is around 250℃ and the heat transfer ratio increases rapidly with a 12% slope around 680℃ which has a high heat transfer ratio in the direction of axis. By the reference (Heribert, 1988 and 1990), heat transfer ratio of H_2 gas is 4.6 times higher with a 55% difference than that of HNx gas.

5.3 Variation of cold spot on the coil temperature.

Though various kinds of width of cold rolled products were produced, of them only two coils of 914 mm and 1219 mm were used.

Figure 11 shows the temperature variation of the cold spot which has the lowest temperature of the coil during the soaking from the #2 thermocouple at HNx gas.

The coil recrystallizes during soaking. The soaking process ends when the temperature of the cold spot approaches the recrystallizing temperature. The soaking was performed after 9 hours for narrow width, but performed after 11.5 hours for wide width.

As it is indicated that the effect of the heat transfer by the convection of the axial direction is larger than that of the radial direction, the cali-

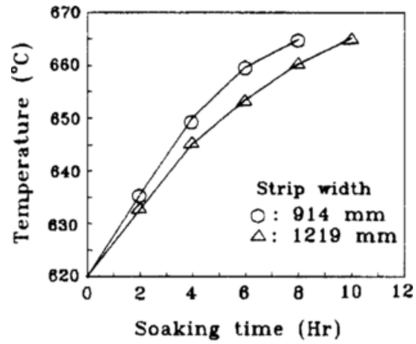


Fig. 11 Variation of cold spot temperature with time during soaking at the HNx BAF.

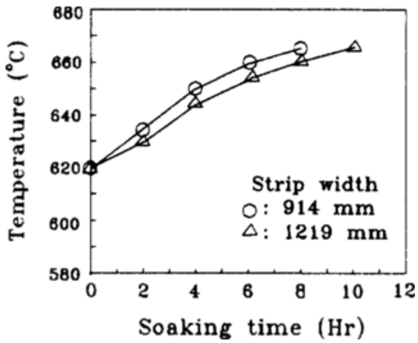


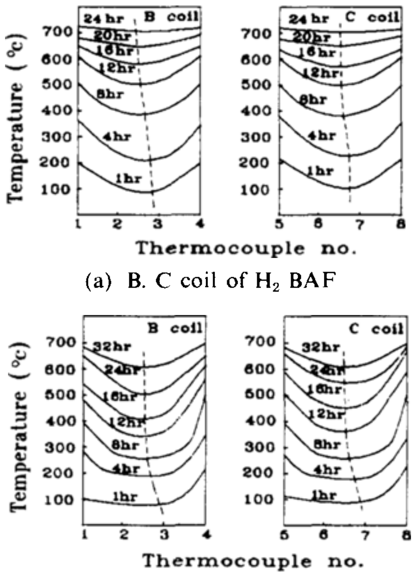
Fig. 12 Variation of cold spot temperature with time during soaking at the H_2 BAF the HNx BAF.

bration time should be determined according to the width of coil rather than the thickness of coil to produce a uniform product quality in BAF.

The temperature variation of the cold spot during soaking in a high efficiency annealing furnace is shown in Fig. 12. It was observed that the trend of temperature increase was almost constant regardless of the width. Because of the fact that in a high efficiency annealing furnace the temperature increase gradient of the cold spot is almost constant regardless of width, it can be inferred that the heat transfer ratio to the radial and the axial direction is larger than that of the HNx gas.

In the case of the narrow width, the soaking in the H_2 BAF takes a total of 8 hours with a fast temperature increase of 6 hours and a slow one of 2 hours. But, the soaking of the wide width requires 10 hours.

This indicates that the effect of heat transfer by



(a) B. C coil of H_2 BAF

(b) B, C coil of HNx BAF

Fig. 13 Variation of cold spot on the coil temperature (dotted line).

convection of axial direction is bigger than by radial direction.

5.4 Variation of cold spot on the coil temperature

The phenomena which Fig. 13 (b) shows are also true in the case of HNx BAF, which indicates that the cold spot moves from the one-third to the center after heating of 32 hours. In the case of H_2 BAF it moves from the one-third to the center after heating of 12 hours, which results from a heat transfer increase to the radius direction.

In the case of H_2 BAF, the cold spot moves to the center of the coil while the temperature is increasing, also in the case of HNx, the cold spot moves to the center from one-third with time by the reference(Perrin, 1989). Accordingly, temperature as shown in Fig. 13 is increasing rapidly during the first heating step, but the temperature increasing rate becomes slower because temperature difference are little between gas and steel.

6. Conclusion

In the annealing processes of steel sheet the effects which the variation of components and flow rates of atmospheric gas have on the cycle time were determined. The variation of the cold spot was also investigated.

The following conclusions are drawn from the results of this study.

① The cooling process is operated somewhat rapidly as the flow rates of the atmospheric gas increase, but if it were not for the variation of the atmospheric gas components, there would be no change in the heating rate. In the high efficiency annealing furnace, which uses different atmospheric gas, the heating velocity is about two times greater than the HNx BAF, and the entire annealing cycle is reduced by approximately 2.7 times.

② When determining the annealing cycle the soaking time is determined according to the width of the coil. For the purpose of consistent quality, the soaking time of the wide width (1219 mm) must be extended for approximately 2 hours longer than the narrow width in the high efficiency annealing furnace, but in HNx BAF for approximately only for about 2.5 hours.

③ In the case of HNx BAF indicates that the cold spot moves to the center after 32 hours of heating. In the case of H_2 BAF it moved from one-third to the center also after 12 hours of heating resulting from a heat transfer increase to the radius direction. Also, cold spot by the reference (Rao, 1983) was one-third from the inside of the coil, as the results of this experiment it is indeed in the center.

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