Abridged version

KAWASAKI STEEL TECHNICAL REPORT
No.9 ( March 1984 )

# A Low (C+N)-13 Cr Martensitic Stainless Steel, RIVER LITE 410DB, for Brake Disk of Motorcycle

Keiichi Yosioka, Shigeharu Suzuki, Bunryo Ishida, Masayoshi Horiuchi, Makoto Kobayashi

Synopsis :
Medium carbon martensitic stainless steels widely used for the manufacture of motorcycle brake disk have some shortcomings such as the indispensability of strictly-controlled quenching for heart treatment of the disk and the deterioration of corrosion resistance due to tempering. RIVER LITE 410DB, newly developed to solve the above problems, is characterized by a high Mn content and an adequate low level of (C+N) content. The high Mn content is aimed to enlarge temperature range in which fully austenitic structure exists at quench temperature, and the control of (C+N) content is to obtain a suitable hardness of martensite formed on quenching. The steel can readily obtain hardness suitable for the brake disk by only quenching without strict control of the conditions for heat treating and is superior to conventional steels in toughness and corrosion resistance.

(c)JFE Steel Corporation, 2003

The body can be viewed from the next page.

# A Low (C + N)-13 Cr Martensitic Stainless Steel, RIVER LITE 410DB, for Brake Disk of Motorcycle*

Keiichi YOSHIOKA ** Shigeharu SUZUKI ** Bunryo ISHIDA ***
Masayoshi HORIUCHI *** Makoto KOBAYASHI ****

*Medium carbon martensitic stainless steels widely used for the manufacture of motorcycle brake disk have some shortcomings such as the indispensability of strictly-controlled quenching for heat treatment of the disk and the deterioration of corrosion resistance due to tempering.*

***RIVER LITE 410DB**, newly developed to solve the above problems, is characterized by a high Mn content and an adequate low level of (C + N) content. The high Mn content is aimed to enlarge temperature range in which fully austenitic structure exists at quench temperature, and the control of (C + N) content is to obtain a suitable hardness of martensite formed on quenching.*

*The steel can readily obtain hardness suitable for the brake disk by only quenching without strict control of the conditions for heat treating and is superior to conventional steels in toughness and corrosion resistance.*

## 1 Introduction

Medium carbon hot rolled martensitic stainless steel plates represented by SUS $420J_1$ and SUS $420J_2$ have been used as a material for motorcycle brake disk that require good corrosion resistance and wear resistance. In the manufacturing process of the disk, the plate is subjected to press-quenching with a water-cooled die after a short electromagnetic induction heating at high temperatures or to tempering after the quenching. The higher the hardness, the higher the wear resistance of the disk, but when it is too hard a disk tends to screech on operation. Therefore, the hardness of brake disk is controlled at 32 to 38 HRC, though with some variation at motorcycle makers.

The brake disk manufacture with only quenching is performed using SUS $429J_1$ in some cases, but since hardness is largely dependent on quench temperature, strict control is required on quality and heat treatment, causing considerable manufacturing problems at motorcycle makers.

In SUS $420J_1$ and SUS $420J_2$, an extremely high dependency of quench hardness on quench temperature requires tempering, causing not only cumbersome processing and added costs, but also the deterioration of corrosion resistance as a chromium depletion zone is formed around chromium carbonitride as a side effect of the tempering.

This explains how significant it is to develop steels that can easily render properties required for disk brake by only quenching.

The authors have overcome the disadvantage of the conventional steels as mentioned above, having developed a low carbon martensitic stainless steel, **RIVER LITE 410DB** (hereinafter abbreviated as R410DB) for the use of motorcycle brake disk. The steel can readily obtain specified hardness required for the disk by only quenching without strict control for its condition, being superior in toughness and corrosion resistance to the conventional steels. R410DB, though mainly used for motorcycle brake disk, can be used for other applications requiring erosion resistance. In this paper, the progress of the development in laboratory examination will be described first, and the characteristics of R410DB will also be introduced.

## 2 Experiment Using Laboratory Ingot

### 2.1 Guideline to the Development

In martensitic stainless steels, generally, the microstructure is very sensitive to heat treatment condition

* Originally published in *Kawasaki Steel Giho*, **15** (1983) 4, pp. 266–272
** Research Laboratories
*** Technical Division
**** Chiba Works

and chemical composition: the amount of austenitic phase at high temperature becomes larger with an increase of temperature up to 1 100°C[1]. The austenite at high temperature transforms to martensite during cooling, and so the quenched-in hardness is determined by the hardness and the amount of martensite formed.

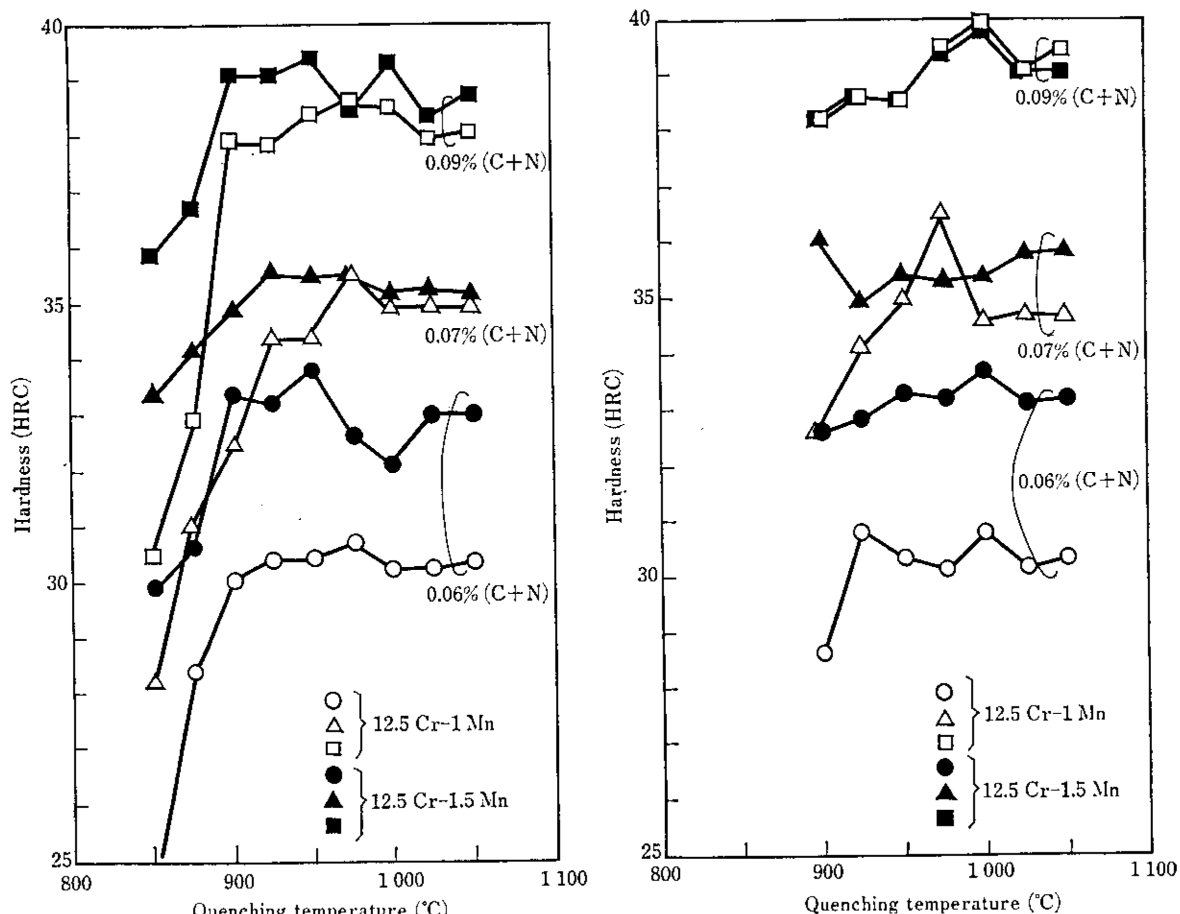
With a view to obtaining specified hardness at a stable level readily from the quenching in a wide temperature range, it was set up as a development guideline to fully enlarge an austenitic temperature range by the addition of Mn, a low-cost austenite former, so that the hardness of martensite formed by the subsequent quenching will be controlled by the (C + N) amount. Thus, an examination was made of the effect of (C + N) amount and Mn addition on the properties of a 13 Cr quenched steel.

### 2.2 Specimen and Experimental Procedure

The specimens used were 30 kg ingots produced by vacuum induction melting, with their chemical compositions shown in **Table 1**. They were basically 12.5%Cr-(0.01–0.015)%N steels containing two levels of Mn content, 1% and 1.5%, and C content ranges

**Table 1** Chemical compositions of specimens (wt %)

| | C | N | Si | Mn | P | S | Cr | C+N |
|---|---|---|---|---|---|---|---|---|
| 12.5Cr-1Mn | 0.045 | 0.014 | 0.16 | 1.03 | 0.023 | 0.005 | 12.55 | 0.059 |
| | 0.058 | 0.011 | 0.15 | 1.03 | 0.024 | 0.005 | 12.46 | 0.069 |
| | 0.081 | 0.010 | 0.15 | 1.02 | 0.023 | 0.005 | 12.43 | 0.091 |
| 12.5Cr-1.5Mn | 0.045 | 0.015 | 0.16 | 1.53 | 0.023 | 0.005 | 12.46 | 0.060 |
| | 0.058 | 0.012 | 0.15 | 1.53 | 0.024 | 0.005 | 12.40 | 0.070 |
| | 0.081 | 0.011 | 0.15 | 1.53 | 0.022 | 0.005 | 12.41 | 0.092 |




(a) 10 min holding (b) 15 s holding

**Fig. 1** Effect of (C + N) content and quenching temperature on hardness (Cooling rate: 30°C/s) from 0.045 to 0.081%. These ingots were hot rolled into 6 mm thick plates and heat-treated at 725°C for 30 min. The plates were heat-treated in an electric furnace at 900°–1 050°C for 10 mm followed by quenching with the cooling rate of 30°C/s, or heat-treated by induction heating at 900°–1 050°C for 15 sec followed by quenching with cooling rates of 5–30°C/s. These heat-treated specimens were subjected to hardness measurement, microstructure observation, Charpy impact test, salt spray test and Ogoshi type abrasion test[2].

The conventional steels in 6 mm thickness, SUS 410, SUS $420J_1$ and SUS $429J_1$, were also examined for comparison.

### 2.3 Effect of (C + N) Content and Quenching Temperature on Quenched-in Hardness

The effects of (C + N) content and quenching temperature on hardness are shown in **Fig. 1**. In 10 min. holding at high temperature, the quenched-in hardness increases with higher quenching temperature, and becomes a constant value, which increases with (C + N) content, within quenching temperature range from 900°C to 1 050°C regardless of Mn content. In a short heating such as 15 sec holding, on the other hand, much addition of Mn lowers the critical quenching temperature at which quenched-in hardness begins to become constant, enlarging the quenching temperature range to obtain a constant quenched-in hardness.

**Figure 2** shows the relation between (C + N) content and hardness obtained by quenching from the temperature range of 925°–1 050°C. In the steel containing 1%Mn, the quenched-in hardness suddenly decreases when the (C + N) content is as low as 600 ppm, while the quenched-in hardness of 1.5%Mn containing steels is linearly proportional to (C + N) content. The microstructures as quenched from 1 000°C are shown in **Photo 1**. The microstructure of the 12.5%Cr-1%Mn steels containing a low (C + N) content exhibits a duplex structure composed of

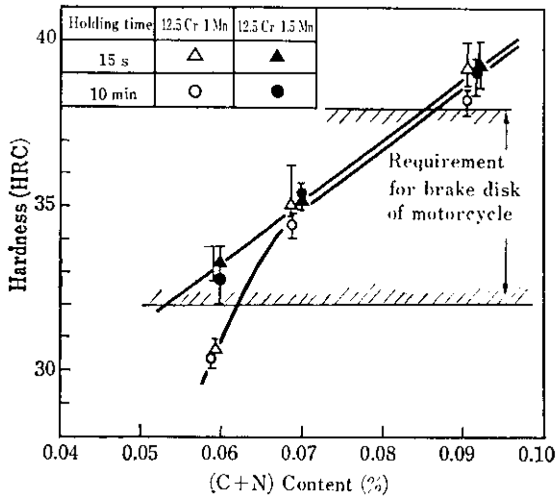



**Fig. 2** Relation between (C + N) content and hardness obtained by quenching from 925°–1 050°C (Cooling rate: 30°C/s)

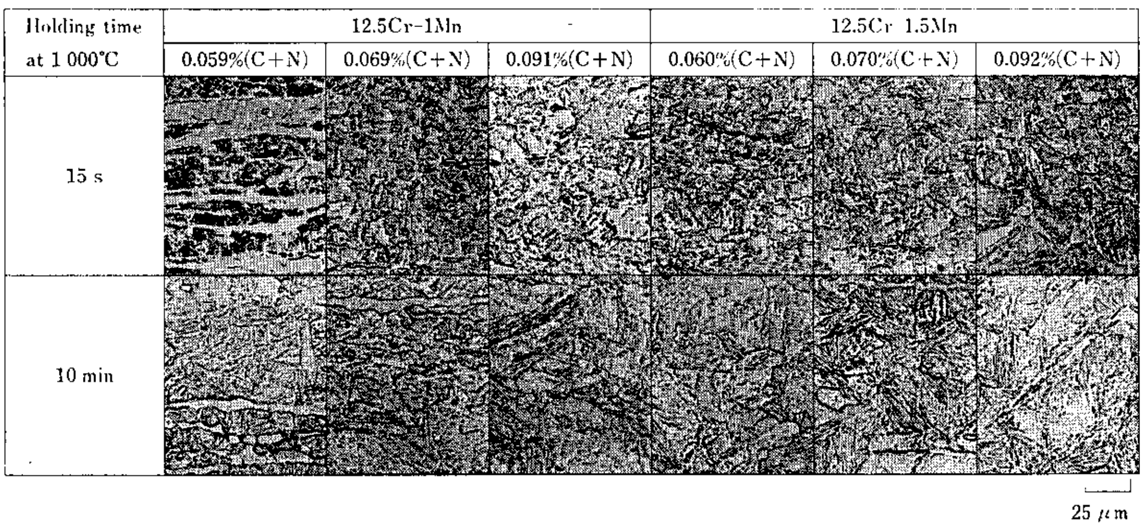



**Photo 1** Microstructure of plates quenched at the cooling rate of 30°C/s after heat treatment at 1 000°C for 10 min

ferrite and martensite. So, the deviation from a linearly proportional relation between (C + N) content and the quenched-in hardness of 12.5%Cr-1%Mn steels is considered to be caused by the forming of ferrite. In 12.5%Cr-1.5%Mn steels, on the other hand, a fully martensitic structure can be obtained even in a low (C + N) content.

As mentioned above, the permissible (C + N) content necessary to obtain the quenched-in hardness of (35 ± 3) HRC depends on Mn content of the steels, increasing with an increase of Mn content. From a steelmaking point of view, therefore, a 1.5%Mn containing steel is more suitable for the application to the brake disk.

The dependency of the hardness of 12.5%Cr-1.5%Mn-0.07% (C + N) steel on quenching temperature is shown in **Fig. 3** in comparison with those of the conventional steels. In the medium carbon martensitic stainless steels such as SUS429$J_1$ and SUS420$J_1$, the dependency is extremely large so that a required hardness is difficult to obtain by only quenching, while the hardness of SUS410 is too low. In a 12.5%Cr-1.5%Mn-0.07% (C + N) steel, the quenched-in hardness remains constant within requirement by quenching from a wide temperature range of 900°–1 100°C.

### 2.4 Effect of Cooling Rate on Quenched-in Hardness

The relation between hardness and the cooling rate after the heat treatment at 950°C is shown in **Fig. 4**.

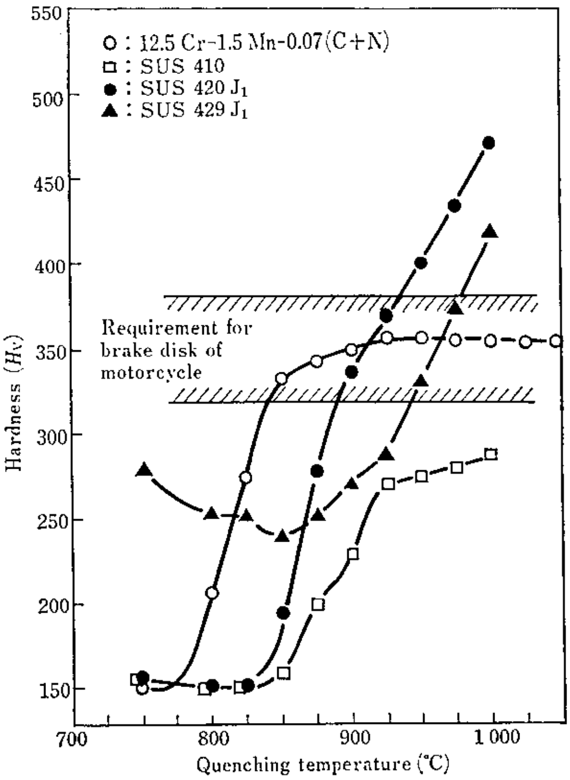



**Fig. 3** Relation between hardness and quenching temperature (Holding time: 10 min, cooling rate: 30°C/s)

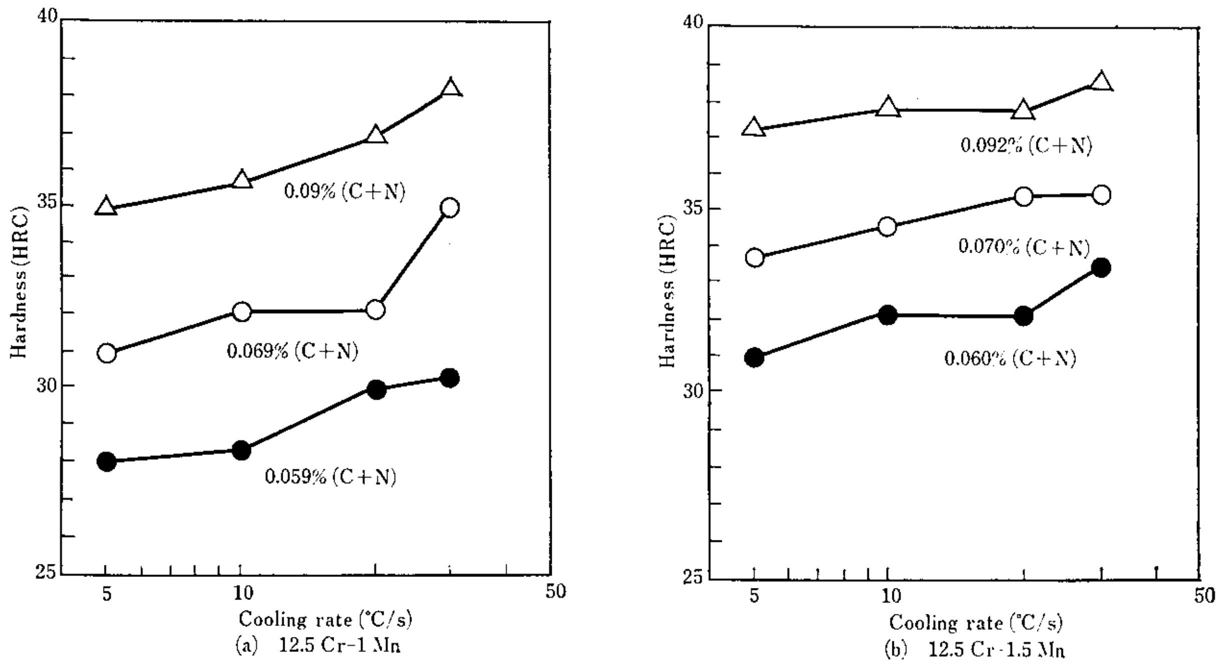



**Fig. 4** Effect of cooling rate after heat treatment at 950°C for 10 min on quenching hardness

In general, hardness has a tendency to decrease with a decrease of cooling rate, which is especially noticeable in 12.5%Cr-1%Mn steels. In 12.5%Cr-1.5%Mn steels, the tendency is extremely small above the cooling rate of 10°C/sec. Their optical microstructure, however, revealed no structural changes due to the differences of Mn content and cooling rate. So, the effectiveness of Mn addition for hardenability is thought to relate to the retardation for the precipitation of sub-microscopic chromium carbonitride at the temperature range from 600° to 700°C during cooling.

### 2.5 Thermal Stability of Quenched-in Hardness

**Figure 5** shows the isochronal curves of hardness of 12.5%Cr-1.5%Mn steels quenched with the cooling rate of 30°C/s after heat treatment at 950°C for 10 min. The hardness remains nearly constant up to 500°C, though a small decrease is caused by the precipitation of cementite at 200°–300°C. In tempering above 500°C, a large decrease in hardness occurs due to the precipitation of $M_7C_3$. However, as the temperature of the brake disk during actual operation is thought to rise at most up to 400°C, a 12.5%Cr-1.5%Mn steel even as quenched is sufficiently fit for the application.

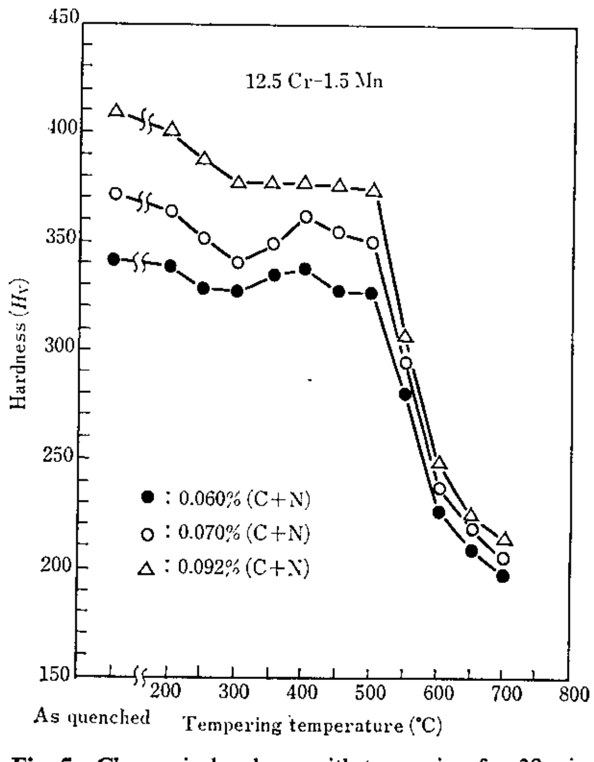



**Fig. 5** Change in hardness with tempering for 30 min (Quenching condition: cooling rate of 30°C/s after heat treatment at 950°C for 10 min)

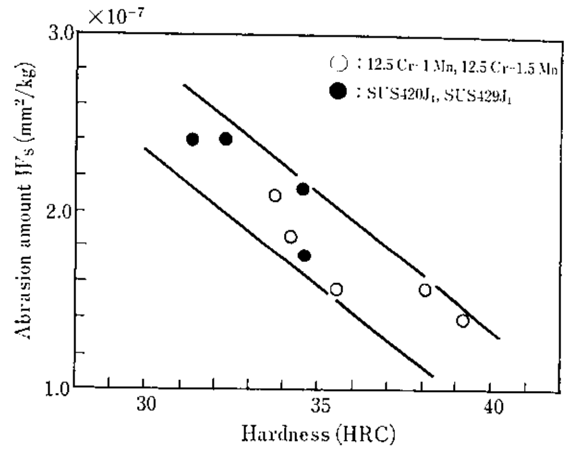



**Fig. 6** Relation between wear resistance measured by Ogoshi type abrasion test and hardness

### 2.6 Wear Resistance

**Figure 6** shows the relation between the hardness of plates and wear resistance determined by Ogoshi type abrasion test, in comparison with those of SUS $420J_1$ and SUS $429J_1$. Wear resistance is in proportion to hardness regardless of the types of the steels. Therefore, the wear resistance of martensitic stainless steels is simply determined only by the hardness, having no relation to (C + N) content.

### 2.7 Mechanical Properties

**Figure 7** shows the relation between Charpy impact value at 20°C and quenching temperature in comparison with that of SUS $420J_1$ whose hardness is controlled to 33 HRC by tempering after quenching. The low (C + N) steels are superior in toughness to SUS $420J_1$, though toughness decreases with an increase of quenching temperature and of the (C + N) content. The degradation in toughness with an increase of quenching temperature is thought to be caused by the coarsening of martensitic structure. In the actual manufacturing process of the brake disk, however, the short induction heating does not seem to bring the degradation in toughness.

**Table 2** shows the mechanical properties of a 12.5%Cr-1.5%Mn-0.07% (C+N) steel plate quenched with the cooling rate of 30°C/s after the heat treatment at 950°C for 10 min in comparison with those of SUS $429J_1$ steel plate with the hardness of 35 HRC controlled by tempering after quenching. The ductility of 12.5%Cr-1.5%Mn-0.07 (C + N) steel is superior to that of SUS $429J_1$.

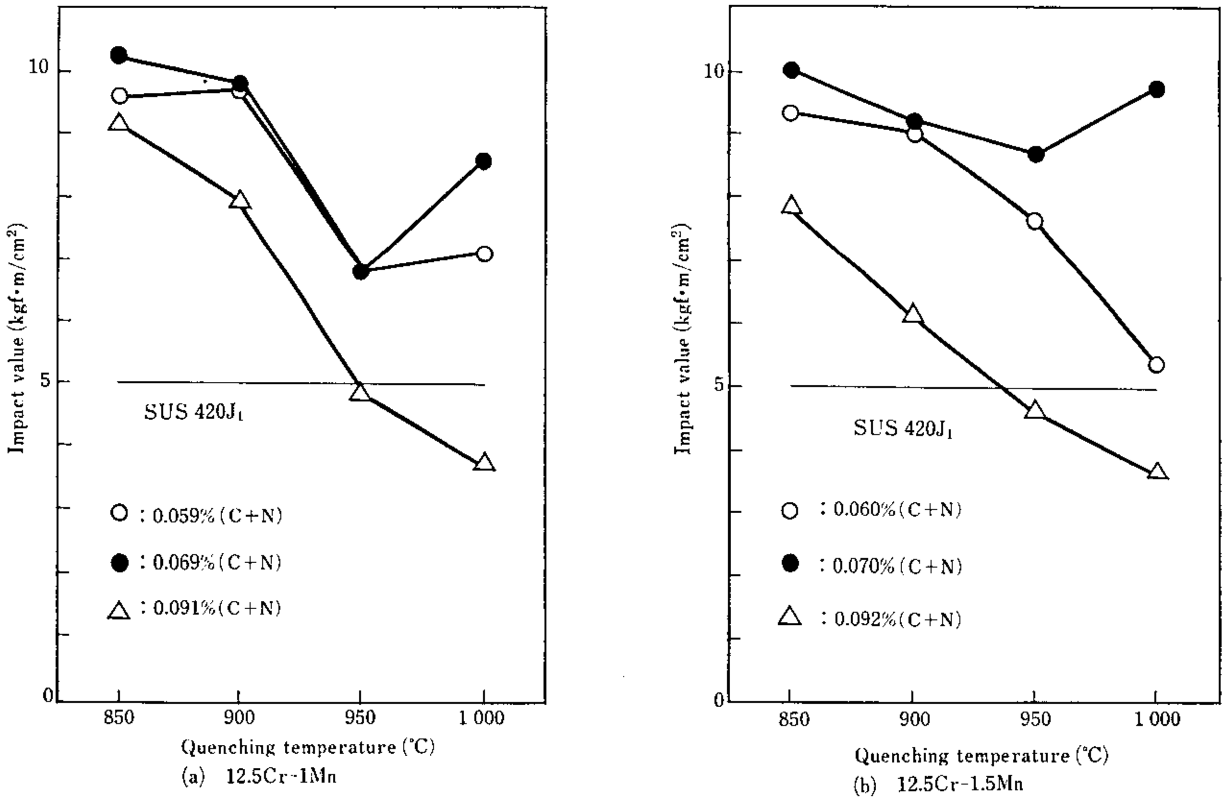



**Fig. 7** Charpy impact value at 20°C for plates quenched at the cooling rate of 30°C/s after heat treatment at 850°–1 000°C for 10 min (JIS No. 4 half sized specimens were used. The value of SUS 420$J_1$ was also shown for comparison, where 420$J_1$ was quenched and tempered at the aim to obtain hardness of HRC 33)

**Table 2** Mechanical properties of plates having the hardness within the specification of brake disk of motorcycle

| | 0.2% proof strength* (kgf/mm²) | Tensile strength* (kgf/mm²) | Elongation* (%) | Hardness (HRC) |
|---|---|---|---|---|
| R 410 DB** | 92.8 | 112.1 | 19.1 | 35.1 |
| SUS 429 $J_1$** | 70.3 | 113.2 | 10.0 | 32.0 |

* JIS No.5 specimen, transverse to rolling direction
** R 410DB and SUS 429 $J_1$ were quenched at the cooling rate of 30°C/s after heat treatment for 10 mm at 950°C and 910°C, respectively

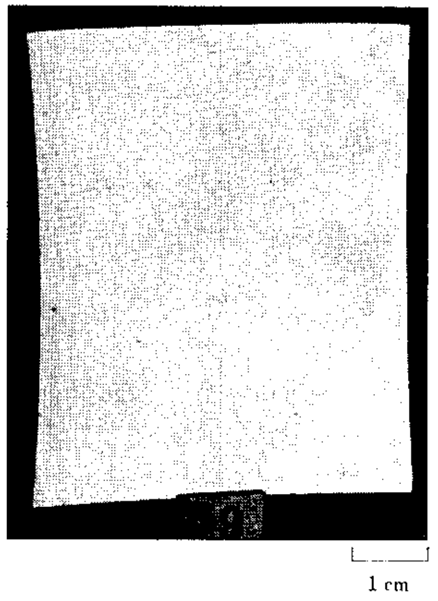



**Photo 2** Appearance of a salt spray test specimen quenched at the cooling rate of 30°C/s after heat treatment at 950°C for 10 min (Testing time: 24 h, #500 polishing)

### 2.8 Rust Resistance

Salt spray test was carried out for 12.5 %Cr-1 %Mn and 12.5 %Cr-1.5 %Mn steel plates quenched with the cooling rate of 30°C/s after the heat treatment at 900°–1 000°C for 10 min. Rusting was not observed in both steels regardless of (C + N) contents and quenching temperatures. The appearances of salt spray test specimens of 12.5 %Cr-1.5 %Mn steel plates quenched from 950°C are shown in **Photo 2**.

## 3 Characteristics of R410DB

### 3.1 Chemical Composition and Manufacturing Process

**Table 3** shows the chemical composition range and the typical example of the low carbon martensitic stainless steel, R410DB, which has been developed on the basic laboratory examination as described above. The steel is characterized by lower (C + N) content than in medium carbon martensitic stainless steel and by the increased addition of Mn.

**Figure 8** shows the typical manufacturing process of R410DB hot rolled and annealed plate.

### 3.2 Mechanical Properties of Hot Rolled and Annealed Plate

**Table 4** shows an example of the mechanical properties of R410DB hot rolled and fully-annealed plate in comparison with those of SUS 420J$_1$ and SUS 429J$_1$. R410DB is superior in ductility and toughness to SUS 420J$_1$ and SUS 429J$_1$.

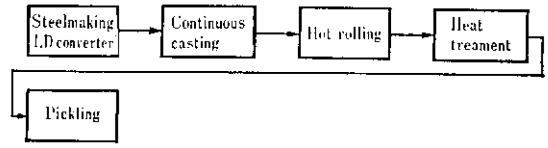



**Fig. 8** Manufacturing process of R410DB hot rolled strip

### 3.3 Quenching Condition in the Manufacturing Process of Brake Disk

**Figure 9** shows the relation between quenched-in hardness and the heat treating condition using induction heating followed by cooling of 30°C/s. The heat treatment below 900°C or short time heat treatment

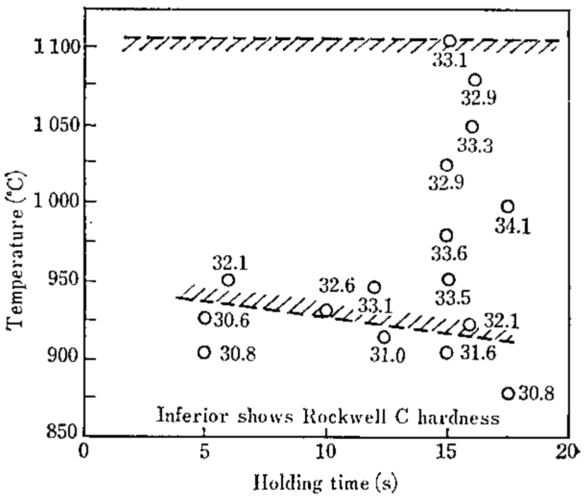



**Fig. 9** Relation between quenching conditions and hardness of R410DB (Cooling rate: 30°C/s)

**Table 3** Specification and a typical example of chemical composition of R410DB

(wt %)

| | C+N | Si | Mn | P | S | Cr |
|---|---|---|---|---|---|---|
| Specification | 0.04~0.07 | ≤1.0 | 1.0~2.5 | ≤0.04 | ≤0.03 | 10~14.5 |
| An example | 0.07 | 0.35 | 1.5 | 0.030 | 0.006 | 12.5 |

**Table 4** Mechanical properties of 6 mm thick hot plate

| Steel | 0.2% proof strength* (kgf/mm$^2$) | Tensile strength* (kgf/mm$^2$) | Elongation* (%) | Charpy impact value at R.T**(kgf·m/cm$^2$) |
|---|---|---|---|---|
| R 410 DB | 20.9 | 43.8 | 30 | 10.0 |
| SUS 420 J$_1$ | 37.2 | 60.4 | 26 | 4.0 |
| SUS 429 J$_1$ | 42.3 | 68.1 | 24 | 3.0 |

* JIS No.5 specimen, transverse to rolling direction
** JIS No.4 half sized specimen, transverse to rolling direction

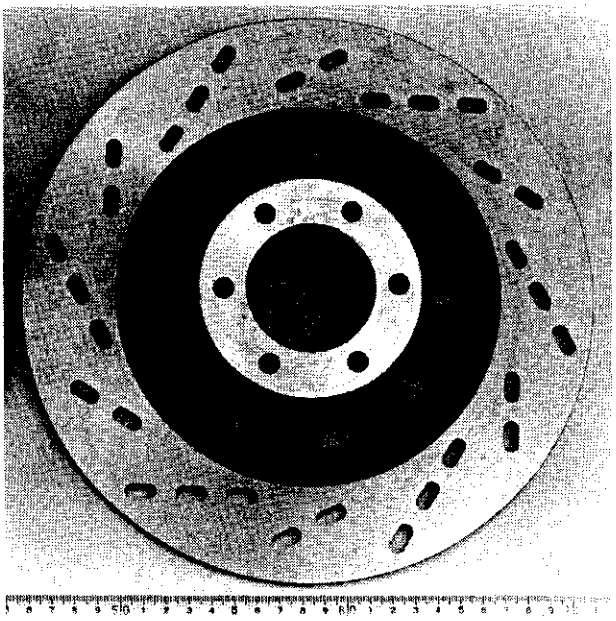


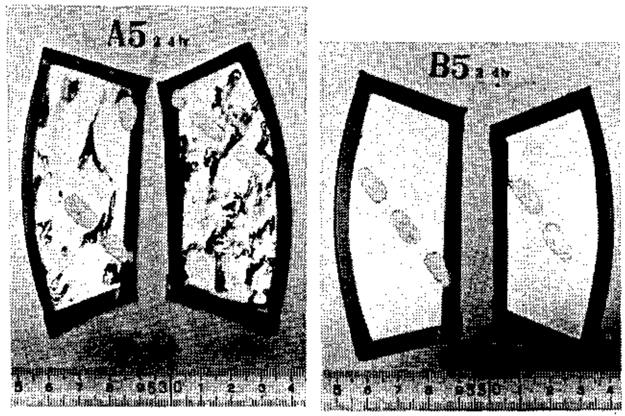
Photo 3 An example of a brake disk of R410DB

such as within 5 sec at 925°C results in a lower quenched-in hardness than required because of the remaining of coarse ferrite. The longer and the higher heating, such as at 925°C or over for 10 sec, leads to a constant hardness within the required range, and to a fully martensitic structure.

Although differing from the heating method used in Fig. 9, the induction heating in the manufacturing process, being a monotonous heating, can basically obtain the required hardness in the condition of the heat treatment illustrated as the hatched region in the figure.

**Photo 3** shows an appearance of the brake disk of R410DB subjected to the heat treatment as described above.

**Photo 4** shows the specimens after salt spray test, taken from the brake disks with the hardness of 35 HRC. The disk of R410DB produced only by quenching exhibits good rust resistance, while that of SUS $420J_1$ is extremely inferior due to tempering after quenching.




$SUS420J_1$ R410DB

**Photo 4** Appearance of salt spray test specimens taken from brake disks of motorcycles (Testing time: 24 h, #500 polishing)

## 4 Summary

Medium carbon martensitic stainless steels have been used as a material of brake disk of motorcycles. These steels, however, have some shortcomings in the heat treatment of the disk, such as indispensability of strict control of the conditions for quenching and deterioration of corrosion resistance due to tempering.

R410DB, newly developed in order to solve the problems as described above, is characterized by high Mn content and an adequate low level of (C + N) content. High Mn content is aimed to enlarge the temperature range in which fully austenitic structure exists at quenching temperature, and the control of (C + N) content realizes a suitable hardness of martensite formed on quenching. The steel can readily obtain the hardness suitable for the brake disk by only quenching without strict control of the conditions for heat treatment, and is superior in toughness and corrosion resistance to conventional steels.

R410DB is suitable for wide uses in a field where existing medium carbon martensitic stainless steels are used after quenching and tempering processes.

### References


1) R.N. Wright and J.R. Wood: *Met. Trans.*, **8A** (1977), p. 2007
2) J. Ogoshi, T. Sada and, M. Mizuno; *Trans. of the Japan Society of Mechanical Engineers*, **21** (1955) 107, p. 555