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Martensitic Stainless Steel "JFE410DB-ER" with Excellent Heat Resistance for Motorcycle Brake Disks†

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Abstract:

Low carbon martensitic stainless steel "JFE410DB-ER" with higher heat resistance and corrosion resistance than conventional steels for motorcycle brake disks has been developed. Effects of Nb and N on the heat resistant properties in 12%Cr-1.5%Mn steel were investigated for the purpose of enhancing heat resistance. Addition of Nb introduced fine Nb(C, N), and thereby prevented temper softening. Addition of N decreased the amount of coarse $M_{23}C_6$ *and increased the amounts of solute (C + N) and fine* $Cr_2(C, N)$*, and thereby prevented temper softening. Additions of Nb and N maintained proper hardness for rotor materials even after tempering at 550°C. Based on these findings, 12%Cr-1.5%Mn-0.13%Nb-0.05%C-0.04%N steel has been developed. The developed steel has excellent durability against temper softening at temperatures exceeding 500°C compared with conventional steels.*

1. Introduction

Figure 1 shows an illustration of a disk brake system. Disk brake systems are widely used for motorcycles because they are effective in radiating heat and stabilizing the brake performance. The disk brake is a system which slows down a motorcycle by frictional force generated when brake pads clamp a rotor rotating in linkage with a wheel from both sides. The rotor needs proper hardness (generally, Rockwell hardness of 32–38HRC) to secure wear resistance and deformation resistance, and also needs sufficient heat resistance to maintain these properties under the heat generated by braking. Corrosion resistance is also required to maintain brake performance and for the reason of appearance. Therefore, martensitic stainless steel, which provides both heat resistance and corrosion resistance, is used as a material for rotors.

Conventionally, SUS420J1 (13%Cr-0.2%C) and SUS420J2 (13%Cr-0.3%C) had mainly been used as rotor materials. However, while these steels have excellent heat resistance, a 2-stage heat treatment process comprising quenching and tempering is necessary to obtain the required hardness, and their corrosion resistance is somewhat inadequate. In contrast, **Fig. 2** shows an effect of quenching temperature on the hardness of JFE410DB (12%Cr-1.5%Mn-0.05%C) and SUS420J2 after quenching. At present, low carbon martensitic stainless steel, as represented by JFE410DB, is mainly used, because proper hardness is obtained by quenching treatment only, as shown here, and corrosion resistance

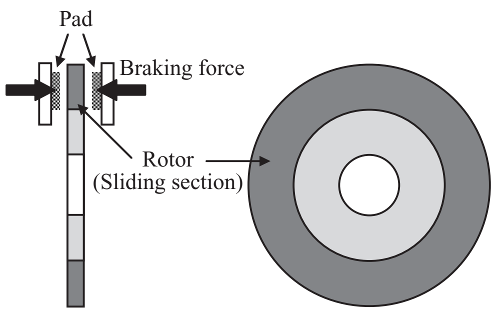

Fig. 1 Schematic illustration of a disk brake system

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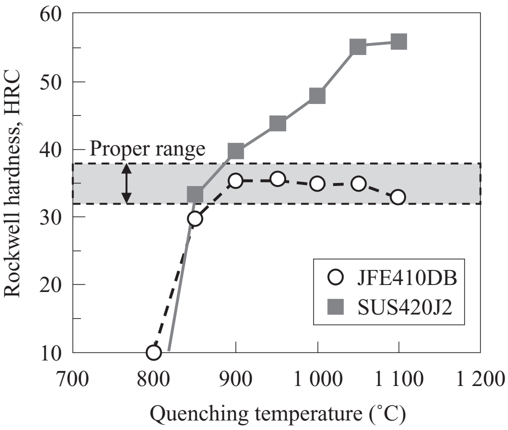

Fig. 2 Quenching hardenability in JFE410DB and SUS420J2 (Specimens were quenched by air cooling after holding at each temperature for 10 min.)

is also excellent[1,2].

In recent years, improved brake reliability suited to higher road performance has become an issue, particularly in medium/large and sports-type motorcycles. In comparison with conventional motorcycles, braking heat generated in these motorcycles is higher, and in some cases, rotors are heated repeatedly to a high temperature exceeding 500°C, increasing the danger of softening of the rotor materials by tempering. Temper softening causes increase of wear and warping of the disk, and leads to reduced brake performance. For this reason, a material having higher heat resistance (temper softening resistance) than that of conventional steel is now required as a rotor material.

In order to meet this requirement, we developed a high heat resistant steel, JFE410DB-ER. The steel is capable of maintaining proper hardness over a long period of time in comparison with conventional steels, even at temperatures exceeding 500°C, by controlling the precipitation morphology of carbonitrides in the steel in the tempering process[3]. This paper describes the technology for achieving high heat resistance and the features of the developed steel.

2. Study of High Heat Resistance

2.1 Development Concept

Martensitic stainless steel is softened in the tempering process due to recovery of dislocations and decreased contents of solute C and N accompanying the precipitation of carbonitrides[4,5]. Therefore, a high heat resistant material was developed based on the existing steel (JFE410DB), focusing on Nb and N. The development concept targeted to delay the recovery of dislocations and improve temper softening resistance by refining carbonitrides and maintaining the contents of solute C and N.

Table 1 Chemical composition

(mass%)

Steel	C	Si	Mn	Cr	N	Nb
A: Base	0.052	0.31	1.54	12.3	0.007	—
B: Nb added	0.079	0.29	1.58	12.4	0.010	0.15
C: High N	0.030	0.31	1.59	12.3	0.043	—
D: Nb added+high N	0.049	0.30	1.57	12.2	0.042	0.15

2.2 Experimental Procedure

Four 12.5%Cr-1.5%Mn steels with different contents of Nb and/or N were prepared, namely, base steel with a chemical composition equivalent to the existing steel, steel with addition of Nb (Nb-added steel), steel with the increased N (high N steel), and steel with added Nb and increased N (Nb + high N steel). **Table 1** shows the chemical composition of the steels.

These steels were melted using a high-frequency vacuum melting furnace and cast into 50 kg ingots. The ingots were heated to 1 200°C and hot-rolled into sheets of 6 mm in thickness. In order to obtain hardness of 90HRB or less, which is suitable for processing brake disks, the hot-rolled sheets were heated at 700–800°C and cooled to around room temperature in the furnace. Then they were quenched by air cooling after holding at 1 000°C for 10 min and tempered at each temperature of 500, 550 and 600°C for 60 min. Heat resistance was evaluated by measuring Rockwell hardness of specimens after quenching and tempering,

In order to clarify the effects of Nb addition and increase of N on heat resistance, the precipitates in the specimens after quenching and tempering treatment were analysed. Observation of the precipitates was carried out by a transmission electron microscope (TEM). The amount of precipitates was measured by chemical analyses of the electroextraction residue using an acetylacetone electrolyte. Identification of precipitates was carried out by the X-ray diffraction method.

2.3 Results and Discussion

2.3.1 Heat resistance (Temper softening resistance)

Figure 3 shows changes in the hardness of the specimens after quenching and tempering treatment. Although no difference can be observed in hardness in the as-quenched condition, in comparison with the base steel, hardness after tempering increased in the order of high N steel, Nb-added steel, and Nb + high N steel. With the Nb + high N steel, which showed the highest temper softening resistance, proper hardness was maintained even after tempering at 550°C. Thus, it was found

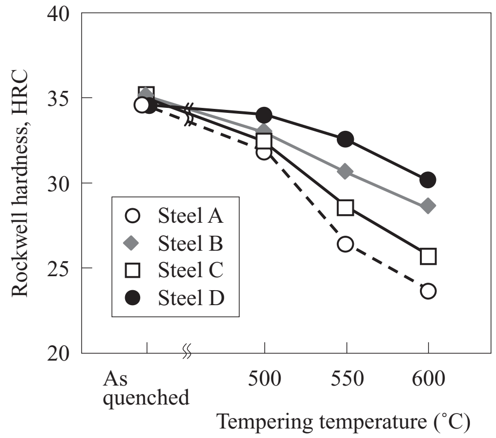

Fig. 3 Effects of Nb and N on temper softening

that the addition of Nb and the increase of N were effective in preventing temper softening and furthermore, a remarkable effect was obtained by the combination of Nb addition and increase of N content.

2.3.2 Effects of Nb and N on heat resistance

The reason for the improvement in temper softening resistance due to the addition of Nb and the increase of N was considered based on a comparison of the precipitates in the specimens after quenching and tempering treatment.

The precipitates in the Nb-added steel and high N steel after tempering at 550°C were identified by the X-ray diffraction method, with the results shown in **Fig. 4**. The results of TEM observation are shown in **Photo 1**. In the base steel, coarse $M_{23}C_6$ precipitates were mainly observed at prior γ grain boundaries. In contrast to this, in the Nb-added steel, fine Nb(C, N) precipitates of 20–30 nm in size were mainly observed in the grains. In the high N steel, fine Cr_2(C, N) precipitates were mainly observed in the grains with a width of several nm and length of several 10 nm, while on the other hand, coarse $M_{23}C_6$ precipitated slightly in comparison with the base steel.

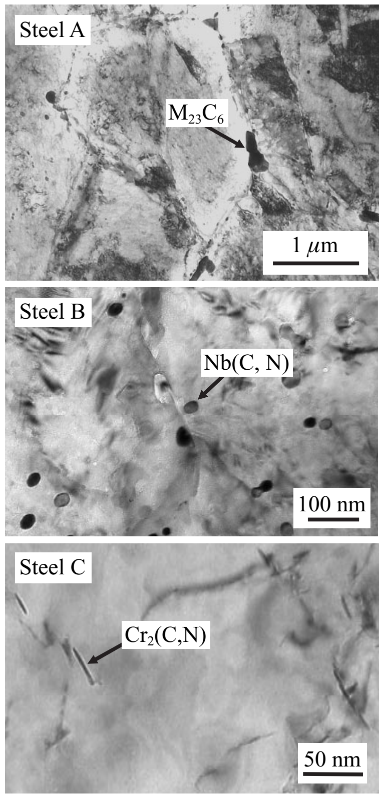

Photo 1 TEM images of precipitates in Steel A(base), B(Nb added), and C(high N) tempered at 550˚C for 60 min

Figure 5 shows changes in the amount of Nb as precipitates with tempering in the Nb-added steel. From the result, it can be understood that most of the added Nb had precipitated as Nb(C, N) in the as-quenched condition. Accordingly, in the Nb-added steel, it is considered that Nb(C, N) improves temper softening resistance by preventing the recovery of dislocations by maintaining a fine size in the tempering process.

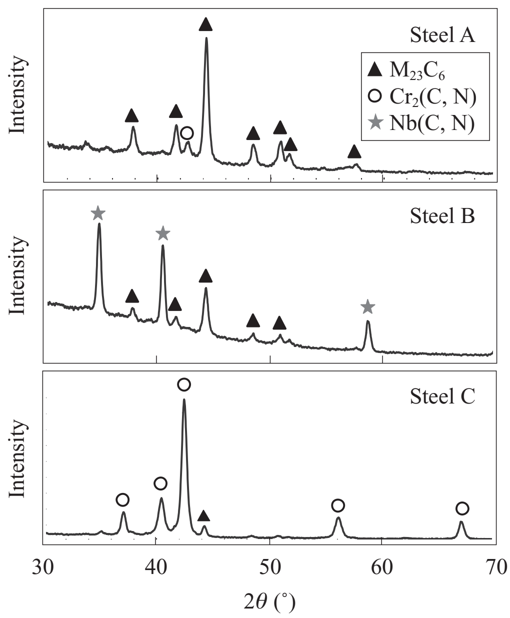

Fig. 4 X-ray diffraction intensity of precipitates in Steel A (base), B(Nb added), and C(high N) tempered at 550˚C

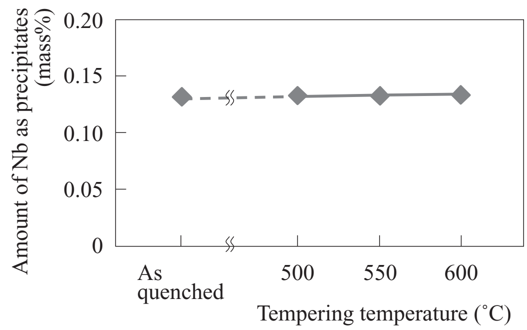

Fig. 5 Amount of Nb as precipitates in Steel B(Nb added) tempered at each temperature for 60 min.

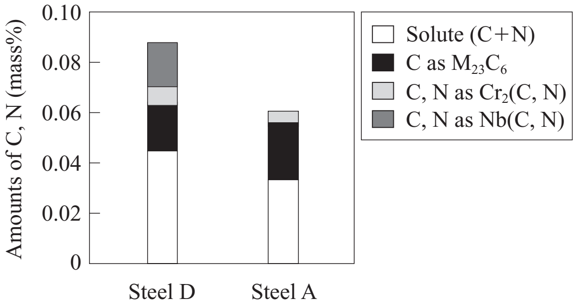

Fig. 6 Amount of solute/precipitated C, N in Steel A(base), and D(Nb + high N) tempered at 550°C

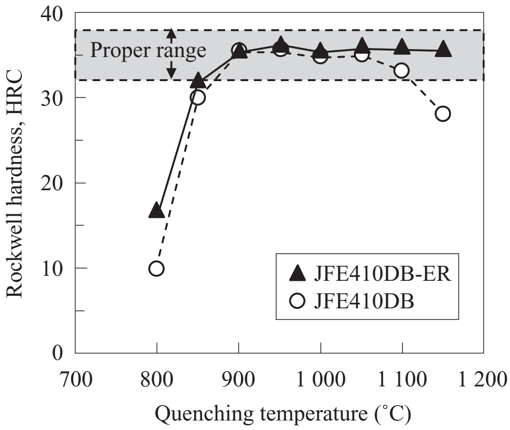

Fig. 7 Change in hardness with quenching temperature in JFE410DB-ER and JFE410DB

On the other hand, in the high N steel, coarse $M_{23}C_6$, which does not contribute to improving softening resistance, decreased in the tempering process, and corresponding amounts of solute C and N increased. Furthermore, it is also considered that the strengthening effect of fine Cr_2(C, N) precipitated in the tempering process supresses the recovery of dislocations, and thereby improves the temper softening resistance.

Figure 6 shows the amount of solute and precipitated (C + N) in the Nb + high N steel after tempering at 550°C as obtained by analysis of the electroextraction residue. The Nb + high N steel shows both the above-mentioned effects of Nb addition and increase of N content. In the Nb + high N steel, it was found that the amount of precipitated (C + N) as $M_{23}C_6$ was small, while not only the finely precipitated (C + N) as Nb(C, N) and Cr_2(C, N) but also the amount of solute (C + N) were larger than that of the base steel.

Accordingly, in the case of Nb addition and increase of N content at the same time, it can be concluded that temper softening resistance is greatly improved by the composite effect of fine Nb(C, N) which had precipitated and remained in the as-quenched condition, and the increased amount of solute (C + N) and precipitation of fine Cr_2(C, N) in the tempering process.

3. Properties of Developed Steel

Based on the above findings, a further study was carried out, examining corrosion resistance, manufacturability and other factors, and thereby, the chemical composition of the new high heat resistant steel for brake disk rotors was decided. **Table 2** shows the main composition of the developed steel, JFE410DB-ER, in comparison with the existing steel (JFE 410-DB). The hardenability, temper softening resistance and corrosion resistance of the developed steel is described as follows.

Table 2 Chemical composition of JFE410DB-ER

(mass%)

Steel	C	Si	Mn	Cr	N	Nb
JFE410DB-ER	0.05	0.3	1.5	12.3	0.04	0.13
JFE410DB	0.05	0.3	1.5	12.3	0.01	—

3.1 Hardenability and Heat Resistance (Temper Softening Resistance)

As an evaluation of hardenability, changes in hardness by quenching temperatures were measured, as shown in **Fig. 7**. The specimens were quenched by air cooling after holding at each temperature for 10 min. The developed steel satisfies proper hardness at quenching temperatures in the range of 850–1150°C, and thus has a wide available quenching temperature range in comparison with the existing steel.

To evaluate heat resistance, temper softening behavior was investigated in the specimens which had been quenched by air cooling after holding at 1 000°C for 10 min. **Figure 8** shows hardness after tempering treatment by holding for 60 min at temperatures in the range of 500–600°C and air cooling. **Figure 9** shows changes in hardness with tempering time in heat treatment at 500°C and 550°C. The developed steel maintains proper hardness even after tempering at 550°C, and the time at which it is possible to maintain proper hardness at tempering temperatures exceeding 500°C is greatly increased in comparison with the existing steel.

3.2 Corrosion Resistance

Corrosion resistance was evaluated by a salt spray test and a pitting potential test on the specimens which had been quenched by air cooling after holding at 1 000°C for 10 min. The salt spray test was carried out for 96 h under conditions in accordance with JIS Z 2371 (5% NaCl solution, 35°C) using a test piece with circular holes simulating the holes in rotors. (The purposes of these holes are for cooling and discharging of wear debris.) The specimens were prepared by drilling holes (8 mmΦ) and finish grinding with #240 to a surface roughness of approximately 1.0 μm. Pitting potential was measured using a corrosive liquid of 0.5% NaCl at

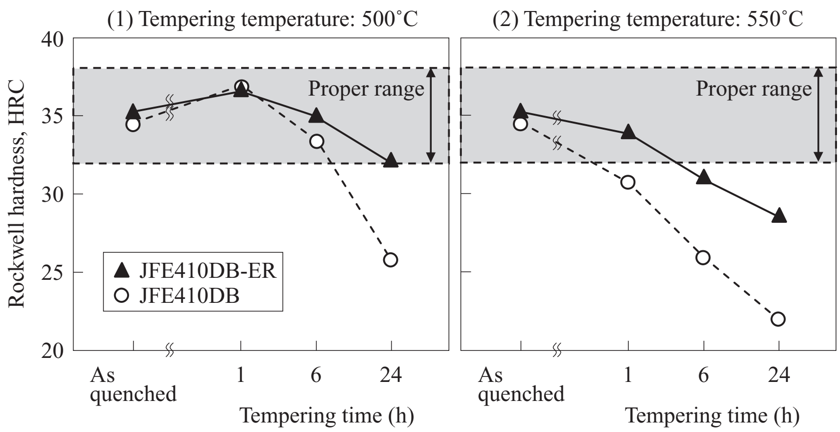

Fig. 9 Change in hardness with tempering time at (1) 500˚C, (2) 550˚C in JFE410DB-ER and JFE410DB

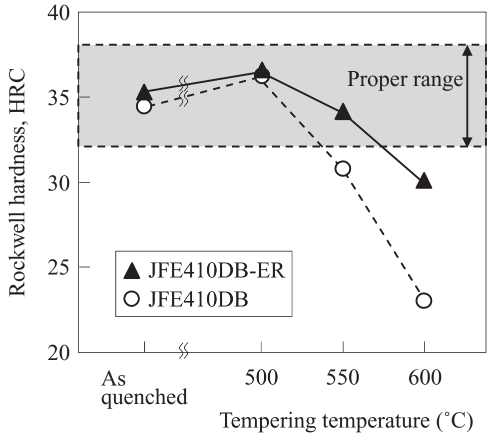

Fig. 8 Change in hardness with tempering temperaturein JFE410DB-ER and JFE410DB

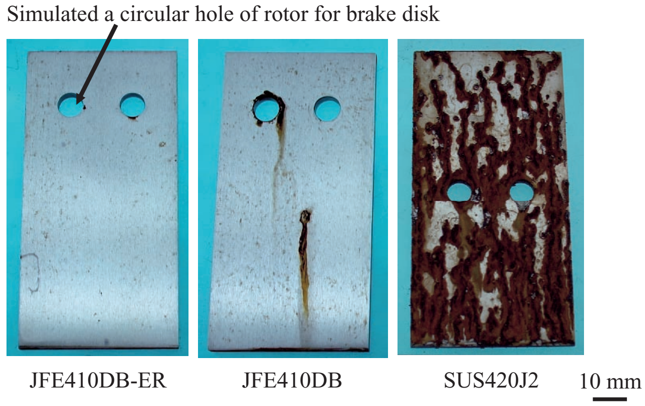

Photo 2 Appearance of salt spray test specimens (testing time; 96 h) in JFE410DB-ER, JFE410DB, and SUS420J2.

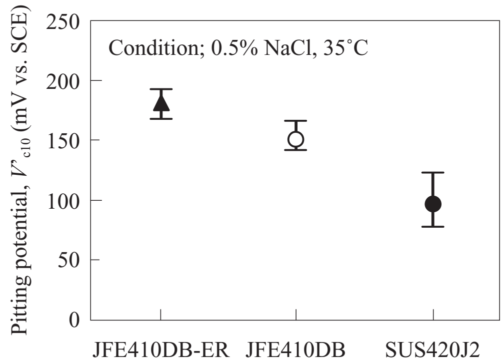

Fig. 10 Pitting potential in JFE410DB-ER and JFE410DB (Specimens were quenched from 1 000˚C.)

35°C. Other conditions were applied in accordance with JIS G 0577. **Photo 2** shows the appearance of the salt spray specimens after 96 h. **Figure 10** shows the results of measurements of pitting potential. With the developed steel, slight rusting can be observed at the edges of the holes, but in comparison with the existing steel, the degree of rusting is light. The pitting potential of the developed steel is also higher than that of the existing steel. The fact that the developed steel has high corrosion resistance in comparison with the existing steel is considered to be due to the decrease of coarse $M_{23}C_6$ at grain boundaries and the increase of solute N content resulting from the increase of N additon[6].

4. Summary

Research was carried out with the aim of improving the heat resistance in low carbon martensitic stainless steel as a material for motorcycle disk brake rotors. Main results were described as follows.

(1) Addition of Nb improves temper softening resistance. It can be considered that the fine Nb(C, N) which had precipitated in the as-quenched condition maintains its size in the tempering process and suppresses the recovery of dislocations.

(2) Increase in the content of N also improves temper softening resistance. The reason for this can be considered that the amount of coarse $M_{23}C_6$ at prior γ grain boundaries, which does not contribute to strengthening, decreases and on the other hand, the increase of solute (C + N) content and the precipitated fine $Cr_2(C, N)$ suppress the recovery of dislocations.

(3) A composite effect of (1) and (2) is obtained by Nb addition and increase of N at the same time, resulting in a large improvement in temper softening resistance.

(4) The developed JFE410DB-ER, which is 12%Cr-1.5%Mn-0.13%Nb-0.04%N steel, maintains proper hardness for rotor material (32–38HRC) even after tempering at 550°C for 60 min, and thus has excellent temper softening resistance in comparison with the existing steel.
(5) The developed steel has high corrosion resistance, showing only slight rusting after a 96 h salt spray test in comparison with the existing steel, and has higher pitting potential also.

5. Conclusion

The developed high heat resistant steel is expected to contribute to improving various problems in connection with disk brake performance, including wear, warping and such of the rotor arising from enhancing road performance in motorcycles. Because the new steel can compensate for decrease in the heat capacity, which is commensurate with the high heat resistance, this material is expected to contribute to more compact and thinner brake disks and greater freedom in brake disk designs.

This paper was prepared based on a revision of a paper entitled “Stainless Steel with Excellent Heat-Resistance through Controlling Fine Carbo-Nitride Precipitates for Rotors of Disk Brakes,” which appeared in the monthly members’ periodical of the Japan Institute of Metals (JIM), “Materia Japan,” Vol. 43, No. 3 (2004), in Japanese.

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