problem, the amounts of addition of Si, Al and other alloy elements were optimized, and it was attempted to increase the (100) and (110) textures, which are favorable for magnetic characteristics, and also to reduce the amount of impurities in the steel[3,4].

)LJXUH shows the magnetic flux density-iron loss balance of the JNE™ Series in comparison with the JN Series, which is the conventional material; φ rl quency of electrical steel sheets which used as core materials will also increase. Furthermore, in case of high speed travel under mainly on the engine power, the motor runs in no-load condition, but in motors that use permanent magnets, high-frequency iron loss occurs due to the alternating magnetic field, and this causes deterioration of fuel economy. Therefore, in electrical steel sheets, increasingly strong demands for reduction of high-frequency iron loss are foreseen. Although iron loss in electrical steel sheets consists of hysteresis loss and eddy-current loss, of these, eddy-current loss increases rapidly due to high frequency magnetic excitation as it is proportional to the square of frequency, as shown in Eq. (1)8).

$$W = (\pi B_m f t)^2 / 6\rho \quad \text{...} \quad (1)$$

where, $_m$: Magnetic excitation flux density, : Frequency, : Sheet thickness and : Resistivity.

In order to reduce eddy-current loss, the two techniques of reducing sheet thickness and increasing resistivity are conceivable. However, reduction of sheet thickness is more effective because, as shown in Eq. (1), eddy-current loss is proportional to the square of sheet thickness. Moreover, it can also be said the reduction of sheet thickness is a desira ¦ ¦ ¦ ¦ ¦ ¦ ¦ kn arsd ˵ M Ţin Ş l n ic kn ᴰ ic ri y-c
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Fig. 9 Magnetic and mechanical properties of high-strength electrical steel sheets

Table 1 Magnetic and mechanical properties of high-strength electrical steel sheets

Grade	Iron loss, $W_{10/400}$ (W/kg)	Magnetic flux density, B_{50} (T)	Yield strength, YS (MPa)	Tensile strength, TS (MPa)	Vickers hardness, HV
35JN250	17	1.67	397	517	213
35JNE-S	23	1.69	480	570	205
35JNT590T	29	1.64	590	640	220

ening, grain refinement, etc. were applied in these materials, and as a result, strength increases of approximately 20% in 35JNE-S and approximately 50% in 35JNT590T were achieved in comparison with the conventional materials.

Application of these materials as rotor materials can contribute to motor downsizing by increasing the maximum rotational speed of the motor and to higher efficiency by suppressing leakage flux as a result of decreasing the width of the rotor bridge.

(OHFWULFDO 6WHHO IRU (36 0RWRUV

In addition to the traction motors of HEV/EV described above, electric power steering (EPS) is a new field for automotive motors. It has been reported that EPS improves fuel economy by approximately 3–5% in comparison with hydraulic power steering[10,11]. This is because the hydraulic pump in conventional hydraulic power steering systems operates at times other than actual steering operations such as cornering and the like, thereby consuming energy wastefully, for example, when the vehicle is traveling in a straight line on an expressway, but in contrast to this, with EPS, the motor is driven only during steering operations, and no energy loss occurs while traveling in a straight line. Because fuel economy is largely improved by installation of EPS, the global market for EPS is expected to grow to 65.5 million units by the year 2020, or an increase of 1.9 times in comparison with 2012 [12].

On the other hand, when EPS is used, the problem of poor steering feeling in comparison with hydraulic power steering has been pointed out[13]. This is due to generation of torque (loss torque) during motor idling, and is caused by mechanical friction such as bearing loss, brush loss, and the hysteresis loss of the core material.)LJXUH shows the relationship between the loss torque of a motor and the hysteresis loss of electrical steel sheets when various types of electrical steel sheets are used in a direct current (DC) brush motor applied in an EPS motors, and indicates that loss torque is decreased by reducing hysteresis loss[2].

Because the hysteresis loss of electrical steel sheets for use in energy efficient motors is small, these materials are considered effective for reducing the loss torque of EPS motors.)LJXUH shows the results of a comparison of the hysteresis loss of the JN Series and the JNE™ Series[2]. The JNE series has lower hysteresis loss in comparison with the JN Series, and thus is suitable as a core material for EPS motors. To confirm the effect of reducing loss torque of EPS motors using the JNE Series, DC brush motors were fabricated and loss torque was evaluated. The results are shown in)LJ [14]. Here, loss torque is shown as a ratio when the value of

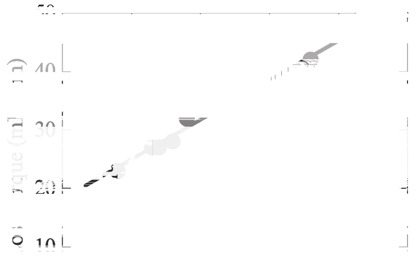

Fig. 10