Ultra-low Sulfur Non-oriented Electrical Steel Sheets for Highly Efficient Motors: NKB-CORE

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A new type of non-oriented electrical steel sheet, NKB-CORE, has been developed by NKK through the application of a unique ultra-low sulfur technology. This type of steel sheet shows: (1) low hysteresis loss; (2) high magnetic flux density; (3) excellent punching property, and (4) low production cost. The low core loss was obtained by reducing the sulfur content in steel and suppressing surface nitriding. The high magnetic flux de

N_2. The magnetic properties of steel sheets processed in this manner were measured by a single-sheet tester at 50 Hz and 60 Hz. Loss separation was performed by applying the two-frequency method.

The cross-sectional microstructures of the steel sheets were observed under an optical microscope. The portions

These results suggest that the increase in hysteresis loss in ultra-low sulfur steel noticeable in **Fig.3** is attributable to the magnetic domain walls being prevented from moving by the small ferrite grain layer and AlN that are present near the surface.

Auger electron spectrometry was applied to the steel sheet surfaces to clarify the causes of increased surface nitriding of the ultra-low sulfur steel. First, in order to clean the surfaces of cold-rolled steel sheet specimens, their surfaces were subjected to Ar ion spattering in an Auger chamber. The specimens were then kept at the elevated temperature for 30 minutes, then cooled to room temperature, and an elemental analysis was performed on the surfaces of the specimens. The temperature inside the chamber was raised to only 850 , since it was difficult to keep the specimens in the chamber at higher temperatures. A prominent sulfur peak was noticed for high-sulfur steel as shown in **Fig.6**. This specimen was subjected to Ar ion spattering for 30 seconds to remove the surface layer, then analyzed again. The sulfur peak had disappeared. This indicates that segregation of sulfur occurs near the surface of high-sulfur steel during the annealing. In contrast, the sulfur peak is very weak in ultra-low sulfur steel, and the segregation of sulfur near the surface is hardly detectable. Driscoll has pointed out that surface segregation of sulfur affects the ability of the steel sheet surface to absorb atmospheric oxygen[6]. From this, it is also conceivable that the segregated sulfur near the surface may interfere with the process of nitrogen absorption. In other words, sulfur in high-sulfur steel conceivably segregates near the surface during the annealing process after hot-rolling and also during the initial period of the final annealing. The sulfur segregated near the surface inhibits nitrogen absorption on the surface during the high-temperature annealing. In the case of ultra-low sulfur steel, sulfur is virtually absent near the surface. Therefore, nitrogen in the atmosphere is easily absorbed though the steel surface during the final annealing, and absorbed nitrogen further diffuses into the interior of the steel. It then combines with Al to form AlN, which in turn precipitates near the steel surface and increases the core loss.

3. Development of an electrical steel sheet for energy efficient motor

3.1 Material design concept

The results of these investigations indicate the following possibilities. Ultra-low sulfur steel is apt to suffer from prominent surface nitriding, but has excellent property in terms of interior grain growth. If the surface nitriding of ultra-low sulfur steel is effectively prevented, core loss will possibly be substantially reduced. Two approaches appeared possible to achieve this objective: (1) to increase hydrogen partial pressure in the annealing atmosphere, and (2) to add elements such as P, Sb, Sn which, like S, tend to cause surface segregation but do not form precipitates that inhibit grain growth. Taking the second option, an element that causes surface segregation was added to ultra-low sulfur steel to prevent surface nitriding and obtain large uniform grains throughout the steel sheet thickness. **Fig.7** shows the degree of nitriding at the depth of 30 m from the surface when 40 ppm of Sb was added to ultra-low sulfur steel. AddiTJ0 -1edstan-5eJ1(tiay ch)-4.9chd 6-4.9bith(u)-5.

Fig.6 Auger spectra of steel surface following annealing

Fig.9 shows the features and key technologies of the newly developed steel. The newly developed steel achieves low core loss by distributing large grains uniformly in the thickness direction. With a lower Si and Al content than in conventional materials, the newly developed steel achieves higher magnetic flux density than that of conventional materials. The lower Si and Al content soften the material, thus making punching operations easier and extending the life of punching dies. Furthermore the lower Si and Al content make the material easier to cold-roll, this in turn has led to higher production yields and cost reductions.

Fig.9 Characteristics of newly developed materials

3.2 Features of the newly developed materials

Figs.10 and **11** show the magnetic properties and Vickers hardness of the 0.50 mm thick newly developed steel sheets. These newly developed steel sheets show higher magnetic flux density than conventional steel sheets that have nearly the same level of core loss. The newly developed steel sheets exhibit 20 to 30 points lower Vickers hardness than the JIS grade materials with comparable

core loss. These improvements make cold-rolling easier,
have 4.8(a)2.1(gnet)3.8(i)3.8(c)2.1(-0.0073a)2.1i(an t)79 TD( )Tj/'

Fig.12 Magnetic properties in high strength magnetic fields

4. Applying newly developed steel sheet to electric power steering

EPS (Electric Power Steering) systems are being in-

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