

Development of steel materials and manufacturing methods for gear usable at high rotation conditions

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Abstract

Electrification causes a high-speed gear rotation and creates a severe (poor) lubrication environment. In this study, a new method to improve the seizure resistance and pitching resistance was developed by modifying the surface of the gear teeth. In addition, this study developed a steel material and its production method that can tolerate high-speed rotation by designing material components to retain the fatigue strength of the root of the gear teeth.

1. Introduction

From the aerodynamic performance and collision safety viewpoints, the miniaturization of the e-Axle is desired.

The motor must be miniaturized to minimize the e-axis. The torque reduction caused by miniaturization should be compensated by a high rotation to secure the power output.

Because of the high-speed rotation of the motor, the reduction gear also rotates at a high speed. This leads to a situation in which the lubrication becomes insufficient, resulting in a poor lubrication environment. In a poor lubrication environment, metal contact on the sliding surface increases, increasing the risk of seizures.

Therefore, we developed a method to prevent gear seizures that is less expensive than conventional seizure resistance methods.

2. Method to improve seizure resistance of gears

Because seizures are caused by metal bonding, they can be suppressed using dissimilar metal layers on the gear surfaces.

For components, such as washers in automatic transmissions, an inexpensive gas soft-nitriding treatment is used to form a compound layer on the sliding surfaces (Fig. 1).

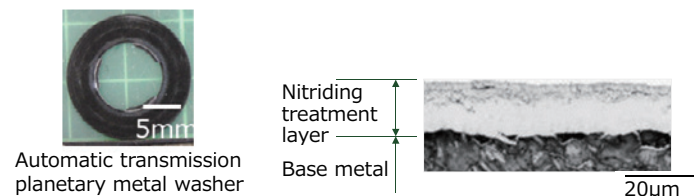


Fig. 1 Surface cross-sectional microstructure after gas nitriding treatment

However, gas soft-nitriding treatment is difficult to apply to gears because gears require high hardness below the surface, whereas gas soft-nitriding treatment can form hardened layers only on the surface.

Therefore, an expensive molybdenum disulfide treatment is generally used for gears (Fig. 2).

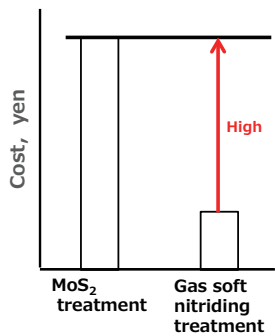


Fig. 2 Cost comparison

In this study, a steel was developed to utilize an inexpensive gas soft-nitriding treatment that can obtain internal hardness by quenching and tempering before the gas soft-nitriding treatment and maintaining the hardness after the gas soft-nitriding treatment.

3. Materials

Table 1 lists the material components of the newly developed gear.

The carbon content was increased to increase the internal hardness of the gears close to that of the existing specifications, and quenching and tempering treatments were applied. Mo and vanadium were added to suppress softening during the gas soft-nitriding treatment.

Table 1 Main material composition (wt%)

	C	Si	Mn	Cr	Mo	V
Development steel	0.34	0.05	0.34	1.12	0.95	0.25
JIS SCr420H	0.21	0.32	0.87	1.18	-	-

Using steel with the developed components, gears were produced during manufacturing (Table 2). Changing the manufacturing process within the range of existing manufacturing conditions is possible.

The results were compared with those of a conventional anti-seizure gear (with molybdenum disulfide treatment) and gear without countermeasures (carburized quenching and tempering treatment).

Table 2 Manufacturing methods comparison

Method		Manufacturing process					
Seizing countermeasure specifications	Development	Quenching and tempering + Gas soft-nitriding treatment	Forging	Machining	Quenching and tempering	Finish processing	Gas soft nitriding treatment
	Current	Carburizing, quenching and tempering + MoS ₂ treatment	↑	↑	Carburizing, quenching and tempering	↑	MoS ₂ treatment
General gear specifications		Carburizing, quenching and tempering	↑	↑	↑	↑	—

4. Metallographic structure and hardness distribution of gears

4.1 Investigation method

The study was performed at the midpoint of the tooth length on the cross section of the middle tooth width (Fig. 3).

The cross-sectional metallographic structures were observed using optical microscopy after corrosion with nital, and the cross-sectional hardness was measured using a Micro Vickers (HV 0.1).

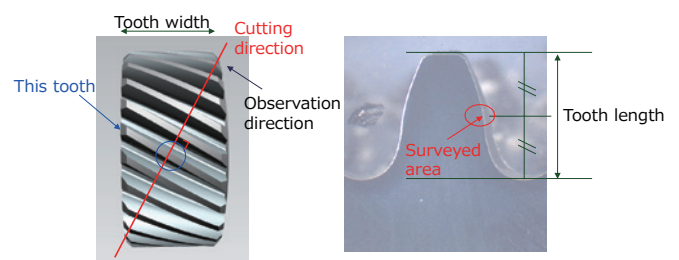


Fig. 3 Gear evaluation cross section

4.2 Results of cross-sectional structure and cross-sectional hardness

Figure 4 shows the cross-sectional structure, and Fig. 5 shows the distribution of the cross-sectional hardness.

Formation of a compound layer was observed on the surface, and a hardness higher than the target hardness was obtained.

The target hardness was estimated from the input of the gear.

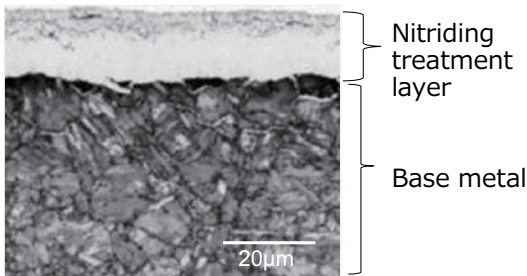


Fig. 4 Cross sectional microstructure

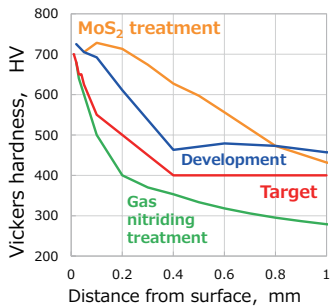


Fig. 5 Cross-sectional hardness distribution

5. Seizure evaluation

5.1 Evaluation conditions

Seizure evaluation was performed using the prototype gear.

These conditions are listed in Tables 3 and 4, respectively. In the evaluation, the rotational speed was varied using two levels of torque that simulated the high-speed running (low torque) and starting (high torque) of the EV car, and the presence of seizures was determined by visual observation.

The rotation speed in the future is expected to surpass 30,000 rpm.

In this study, an input of 30,000 rpm was not possible owing to the limitations of the test machine. Therefore, by raising the evaluation oil temperature, where oil film formation becomes difficult, a severe lubrication condition was created, and the seizure resistance was evaluated under a condition equivalent to more than 2 times the speed (30,000 rpm) of the current EV (Fig. 6).

The evaluation time under each condition was set to be 3 min.

Table 3 Low torque evaluation experimental conditions (high speed driving simulation)

Number of rotations, rpm	4,000	5,000	...	10,000
Torque, Nm	202	202	...	202

↑ Observation
↑ Observation
↑ Observation
↑ Observation

Table 4 High torque evaluation experimental conditions (simulating starting)

Number of rotations, rpm	1,000	2,000	...	7,000
Torque, Nm	625	625	...	625

↑ Observation
↑ Observation
↑ Observation
↑ Observation

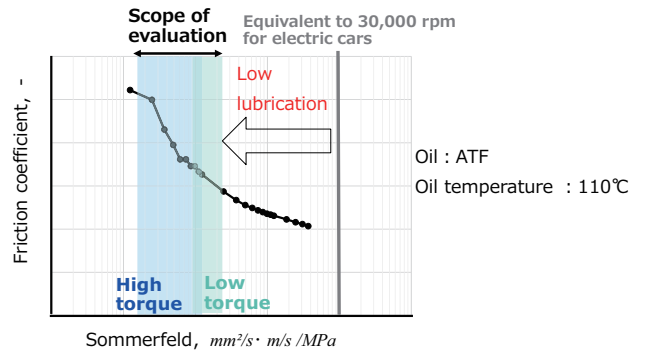


Fig. 6 Stribeck curve

5.2 Evaluation Results

(1) Low-torque condition

Seizures were evaluated at the upper-limit rotation speed of the test machine. Neither the specimen with the developed component specifications nor molybdenum disulfide treatment caused seizures. The seizure resistance of the specimen was approximately twice as high as that of the sample subjected to carburizing, quenching, and tempering treatments (Figs. 7 and 8).

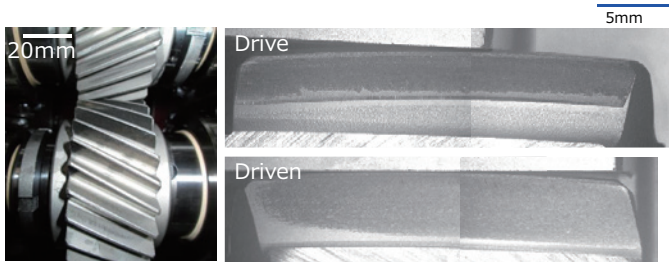


Fig. 7 Development specifications external view (after low torque evaluation test)

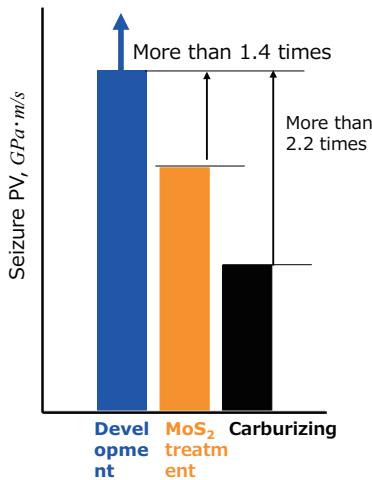


Fig. 8 Endurance test results (low torque test)

(2) High-torque condition

Gears with the developed component specifications resulted in no seizures and achieved over 2.2 times seizure resistance compared to gears with carburizing, quenching, and tempering treatment, and over 1.4 times seizure resistance compared to gears with molybdenum disulfide treatment (Figs. 9 and 10).

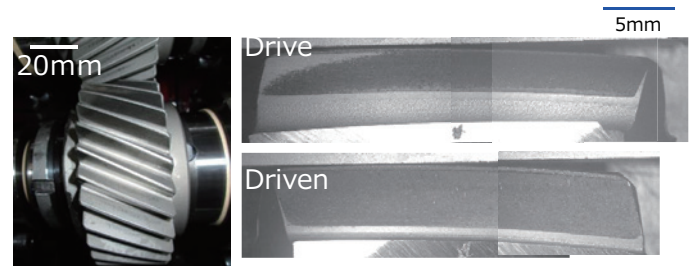


Fig. 9 Development specifications external view (after high torque evaluation test)

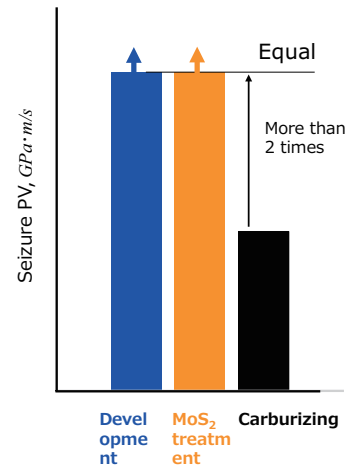


Fig. 10 Endurance test results (high torque test)

6. Discussion

In the evaluation under high-torque conditions, the developed component specifications enabled seizure resistance over 1.4 times compared to the molybdenum disulfide treatment. In the evaluation under low-torque conditions, neither patient showed seizures.

Because no significant difference was observed under the low-torque condition between the gears with the developed component specifications and the molybdenum disulfide treatment, the tooth surface after the test under the low-torque condition was studied. It was found that the friction consumption of the gear with the developed component specification, which has a hard coating layer, was approximately $4 \mu\text{m}$, while that of the gear with the molybdenum disulfide treatment was approximately $16 \mu\text{m}$, nearly 4 times larger (Figs. 11 and 12).

Compared to the molybdenum disulfide treatment, the developed component specification exhibits a higher abrasion resistance necessary for retaining the protecting layer and, thus, is superior in terms of seizure resistance even under low torque conditions.

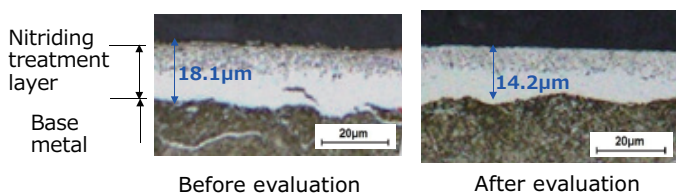


Fig. 11 Film thickness before and after evaluation tests of development specifications

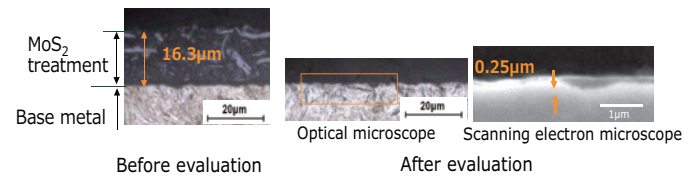


Fig. 12 Film thickness before and after evaluation tests of MoS₂ treatment

7. Summary

We developed a material and processing method that improves the seizure resistance of gears in high-speed motor rotation.

The combination of high-alloy steel components, quenching and tempering treatment, and gas soft-nitriding treatment achieved higher seizure resistance than molybdenum disulfide treatment, which is the conventional method to obtain seizure resistance.

It was possible to make the improved gears cheaper than with molybdenum disulfide treatment because the manufacturing process was changed only within the range of the existing manufacturing conditions.

8. References

Toshihiro Oda, Gou Katou, Tomoya Tamai, Ayumi Yamazaki: Development of gear materials and manufacturing methods to improve gear resistance in low-lubrication environments, Chubu Branch Research Presentation 2023, Hitotek Nagoya.

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