

Development of High-performance Gear Materials

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ABSTRACT

Two types of steel, a high pitting-toughness material displaying excellent performance in relation to the gear tooth fatigue characteristic and a high yield strength material displaying excellent tooth bending toughness, were developed for use in Formula One gearboxes. Optimization of the alloy composition increased pitting toughness, contributing to the achievement of a 740 g weight saving by enabling the thickness of the gear teeth to be reduced. The high yield strength gear material displayed a yield strength in excess of 1900 MPa, and was developed to ameliorate the issue of tooth root fatigue damage originating in bending of the gear teeth under the excessive input forces characteristic of Formula One racing. From 2008, regulations were changed to stipulate the use of a single gearbox for four race events, and the new material contributed to the achievement of increased long-distance reliability.

1. Introduction

At the commencement of the development program for Honda's Third Formula One Era, gears manufactured by Xtrac from a material corresponding to SNCM815VA were employed in the BAR Honda Formula One gearbox. However, in 2001, there was a frequent occurrence of tooth pitting on the final drive gear. The need for a high pitting-toughness gear material therefore increased, and attention was focused on the development of a new material.

Bending of the gear teeth due to extremely high input forces, as for example at the start of a race, also represented an issue. Changes in Formula One regulations in 2008 stipulated the use of a single gearbox for four race events, and a development program for a high yield strength gear material was therefore conducted in order to increase tooth bending toughness. The target value for tooth bending toughness was set 20% higher than the target for high pitting-toughness material, and the target value for 0.2% yield strength was set at 1900 MPa and above (40% higher than the target for high pitting-toughness material).

2. Development of High Pitting-toughness Material (LBHD-2E)

2.1. Developed Technology

In order to increase the pitting toughness of gear teeth, it is important that the hardness of the tooth surface should not decline (i.e. the tooth surface should not soften) even at high temperatures⁽¹⁾. Table 1 shows

Table 1 Chemical composition

(mass%)

	C	Si	Mn	Ni	Cr	Mo
Conventional steel SNCM815VA	0.12- 0.18	0.15- 0.35	0.30- 0.60	4.00- 4.50	0.70- 1.00	0.15- 0.30
Developed steel LBHD-2E	0.30	1.50	0.35	2.00	1.50	0.75

the chemical composition of the developed steel, in which the amount of Si, Cr, and Mo, elements that increase resistance to temper softening, was optimized. A triple melt process was used to manufacture the steel in order to reduce the incidence of inclusions, which can be the origin points for tooth pitting, enabling production of a high-cleanliness material.

2.2. Effects on Performance

Figure 1 shows the surface hardness profile of the conventional and developed steels after heating to 300°C following carburization. The decline in surface hardness is controlled in the developed steel, LBHD-2E, in comparison to the conventional steel, SNCM815VA, and it displays a higher resistance to softening at high temperatures.

Figure 2 shows the results of a gear tooth pitting test using race gears. LBHD-2E displays more than twice the pitting toughness of SNCM815VA in terms of life cycles. LBHD-2E was employed in races from 2004 onwards, and enabled the achievement of a weight saving of 740 g through the reduction of the thickness of the gear teeth.

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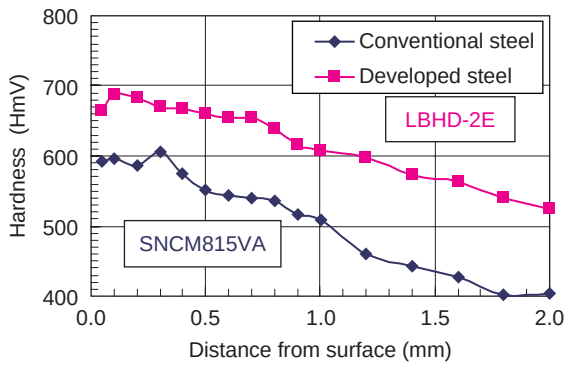


Fig. 1 Comparison of hardness profile of conventional and developed steel after 300 °C heating test

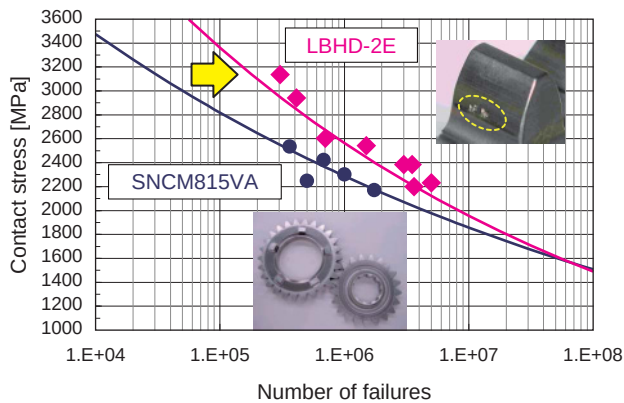


Fig. 2 SN diagram of gear tooth pitting

Table 2 Chemical composition

	(mass%)					
	C	Si	Mn	Ni	Cr	Mo
Conventional steel LBHD-2E	0.30	1.50	0.35	2.00	1.50	0.75
Developed steel 250STF5	0.52	2.50	0.70	1.80	0.80	0.40

Table 3 Comparison of mechanical properties

			0.2% YS MPa	TS MPa	EL %	Core hardness
Conventional steel	1	SNCM815VA	1029	1308	18.6	42 HRC
	2	LBHD-2E	1332	1795	15.9	52 HRC
Developed steel		250STF5	2137	2493	6.5	59 HRC

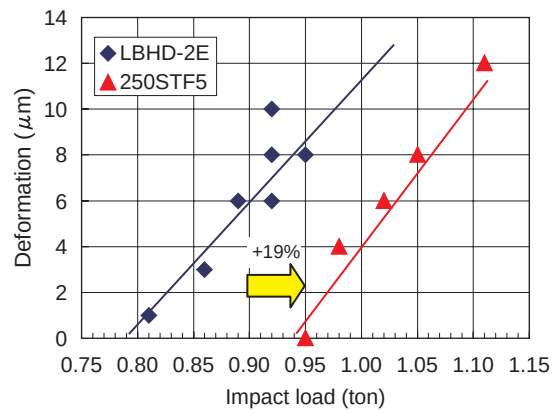


Fig. 3 Result of tooth bending test

3. Development of High Yield Strength Gear Material (250STF5)

3.1. Developed Material

The development of a high yield strength material was conducted with high-Si steel⁽²⁾ as the base material, given that it enabled the achievement of a balance between high yield strength and high toughness, and was a material for which carburization could be used to harden the surface layer. The amount of C added was increased to achieve high hardness in the matrix, and the amount of Si added was increased to increase resistance to softening. Because Si also promotes grain oxidation, low pressure carburizing was selected as the carburizing method. Direct quenching was employed during the carburizing treatment and temperature conditions were optimized in order to prevent grain growth. Table 2 shows the chemical composition of 250STF5, the developed steel, and Table 3 shows its mechanical properties. The material satisfied the target of 1900 MPa or higher for 0.2% yield strength, reaching a figure of 2137 MPa.

3.2. Effects on Performance

Figure 3 shows impact loads and bending deformation in tooth bending tests conducted on a pair of gears. Compared to the previous steel, LBHD-2E, the

load at which the teeth commenced bending was 19% higher for the developed steel.

Tooth bending tests in an actual gearbox also showed that the load at which the teeth commenced bending was 24.8% higher in the developed steel as a percentage of input torque. 250STF5 was employed in races from 2008.

4. Conclusion

A high pitting-toughness material was developed, and was employed for ratio gears in races from 2004. This helped to enable the thickness of the gear teeth to be reduced by 20%, contributing to the realization of a weight saving of 740 g in the gearbox as a whole. The material was later also employed for the final gears and the dog rings, contributing to the achievement of increased reliability against gear tooth pitting.

A high yield strength gear material was developed that exceeded development targets, achieving a yield strength of 2137 MPa, 60% greater than that of the previous steel. When the developed steel was employed in a gearbox, the load at which the teeth commenced bending was increased by 24.8%. This material was used for the 1st gears and shaft from the opening race of 2008, and contributed to the achievement of increased reliability over long distances, as necessitated by the

regulation stipulating the use of a single gearbox for four-race events.

Acknowledgments

The authors wish to take this opportunity to thank the staff of Daido Steel Co., Ltd., for their generous assistance in materials development and gear tooth bending tests during the course of the projects discussed in this paper.

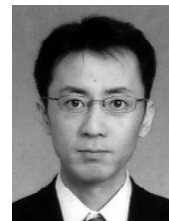
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