

Development of Thermal Fatigue Resistant Ferritic Cast Steel for Turbine Housing of Diesel Engine Automobile

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ABSTRACT

In recent years, the temperature of automobile exhaust gas is on a rising trend due to lowering pollutant emissions and improving fuel economy, and exhaust gas temperature reaches as high as 1173K in the case of diesel engine cars. Against this background, Ni-resist D-5S cast iron has been chosen extensively as a turbine housing material for the diesel engine cars. But, Ni-resist D-5S has become a material of great cost volatility due to high Nickel content of 35 mass%, which price is expensive and unstable. On the contrary Ferritic cast steels, which possesses favorable thermal fatigue properties and good material cost stability, are considered to be promising substitutions for the Ni-resist D-5S. However conventional ferritic cast steels have relatively high melting points, which cause poor castability. For this reason, new ferritic cast steel, StarCast DCR3, has been developed by optimizing the chemical composition with keeping of the advantage of castability, productivity high temperature strength, and thermal fatigue properties such as crack and deformation resistance. Therefore, StarCast DCR3 is considered to be an effective material for turbine housing application up to 1173K.

efficiency as an effective means to improve fuel economy. Generally speaking, the smaller engine leads to lower engine power output and enhance the higher combustion efficiency leads to higher exhaust gas temperature. For this reason, a turbocharger, which used to be regarded as an extra item among the engine components, has become a major indispensable component of an engine to assist the lowered power for the smaller engine. Further, the material of the turbocharger has been demanded excellent heat resistance at higher temperature. A turbine housing is one component of the turbocharger and requires thermal fatigue property because it is used in cyclic heat condition fixed with the engine. The following three approaches are considered as method to enhance thermal fatigue resistance: [Method 1] To lower thermal stress, since thermal stress generated in a heat cycle is expressed with the formula (1). [Method 2] To give a material with the sufficient high temperature strength, which withstand expected thermal stress. [Method 3] To raise oxidation resistance, which causes as an initiation of crack.

$$\sigma_T = E \cdot \varepsilon = E \cdot l (T_1 - T_0) \cdot \cdot \cdot \cdot (1)$$

σ_T : Thermal stress

ε : Strain

E : Young's modulus

l : Mean coefficient of thermal expansion

T_1 : Maximum temperature

T_0 : Minimum temperature

INTRODUCTION

Recently, reduction of CO₂ emissions has become a mandatory requirement due to environmental regulation, and the improvement of fuel economy is recognized as one of the key issues in the automotive area. To achieve this, automakers are actively promoting R&D to downsize engine volume or enhance combustion

Different materials are chosen conventionally for application to turbine housing depending on exhaust gas temperature as shown in Figure 1. Cast iron materials are used for diesel vehicles, of which the exhaust gas temperature is relatively low, while cast steel materials are used for gasoline vehicles, which are exposed to higher exhaust gas temperature. In practice, Ni-resist D-5S (JIS FCDA NiSi-Cr 35 5 2: spheroidal graphite austenitic cast iron) is used widely with thick-wall designs, and demand for heat resistant ferritic cast steels has been low because of their high melting points and unfavorable productivity, although the ferritic cast steels show better thermal fatigue resistance in the allowable operating temperature range from 1073 to 1173K. Because of unstable price of raw material Ni, however, the heat resistant ferritic cast steels^[1~5] are being reevaluated again, in terms of stable cost and superior characteristics. Conventionally used Daido Steel's heat resistant cast steel DCR1 is quite superior thermal fatigue resistance to Ni-resist D-5S, while the productivity is not exactly sufficient owing to high melting temperature as mentioned above. In view of these backgrounds, we set our objective to develop the heat resistant ferritic cast steel based on DCR1 for turbine housing application that provides superior castability and thermal fatigue resistance simultaneously.

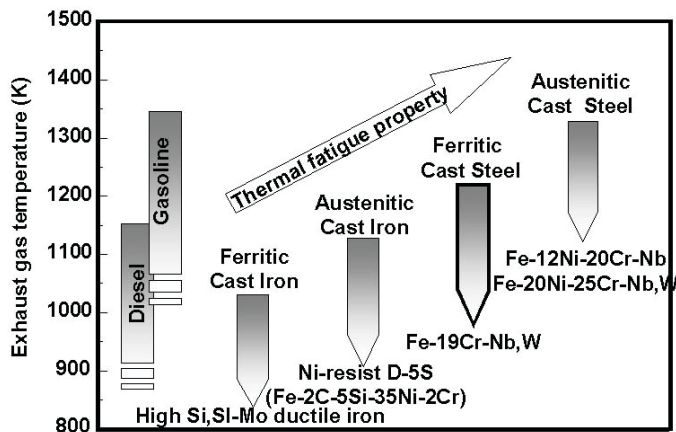


Figure 1 Relation between using material and exhaust gas temperature.

ALLOY DESIGN

The concept of alloy design is shown in Figure 2. Firstly, we aimed at improving castability by lowering the melting point, and, at the same time, keeping high temperature strength by precipitation hardening. In order to lower the melting temperature, addition of carbon was examined. However, the addition of C would induce the formation of the austenite (γ) phase and lower α - γ transformation point (so called A_{c1} point), so that the thermal fatigue resistance might be deteriorated by formation of martensite phase^[6]. Hence, the content balance of carbon and ferrite forming elements as Nb and W were calculated by Thermo-CALC

thermodynamics software, to obtain the matrix phase with only ferrite under the target service temperature, 1173K. The composition of the conventional DCR1 and the developed DCR3 are shown in Table 1. The developed DCR3 contains more C and Nb, increased by 0.30 and 0.5 mass % respectively from the conventional DCR1, and less W, decreased by 1 mass %.

Increase of thermal fatigue

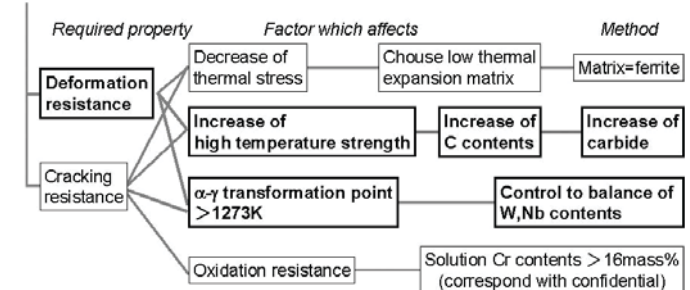


Figure 2 Alloy design concept.

Table 1 Representative compositions.

Alloy	Representative composition (mass%)				
	C	Cr	Nb	W	Fe
Conventional DCR1	0.05	19.0	1.0	2.0	bal.
Developed DCR3	0.35	19.0	1.5	0.7	bal.

EXPERIMENTAL PROCEDURES

TEST SAMPLES

The following test samples were melted in a 150 kg induction furnace at air. The metals were cast into JIS G 0307 B type ingot molds between 1773 and 1823 K, and they underwent an annealing process at 1223 K for 3.6 ksec and were air cooled before the experimental. On the other hand, D-5S was cast into JIS G 0307 A type ingot molds after molten in an induction furnace and put to tests without further heat treatment. An optical microscope and SEM were used for the observation of microstructures. Then, to identify the kind and the amount of carbides, XRD and SEM-EDX analysis were carried out.

TEST PIECES AND THEIR TESTING METHODS

Thermal expansion - By a differential dilatometer, thermal expansion coefficient from room temperature was measured with Alumina reference as the standard sample.

Young's modulus - For Young's modulus measurement, the horizontal oscillation resonance method was used in accordance with the standard of JIS Z 2280 (ASTM E1875). The measurements were taken at every 100 °C.

or so with the temperature raised at a rate of 0.042 K/sec.

Tensile property - Tensile properties were measured by using flanged type II test pieces in the temperature range of the room temperature to 1273 K, according to JIS G 5067.

Oxidation resistance - Cyclic oxidation tests were performed according to JIS Z 2282 at 1173 K for 720 ksec in an air atmosphere. The oxide scale formed on the surfaces was removed with a nylon brush, then the mass change was measured, and the mass gain per unit dimension by oxidation was calculated.

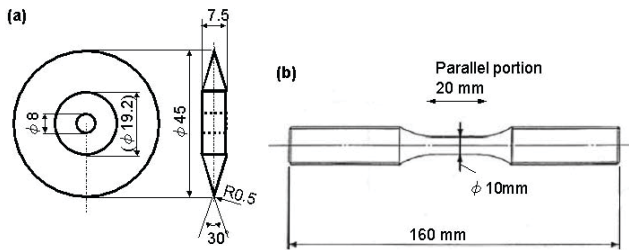


Figure 3 Shapes and size of specimens. (a) Fluidized bed type and (b) axial force type thermal fatigue test.

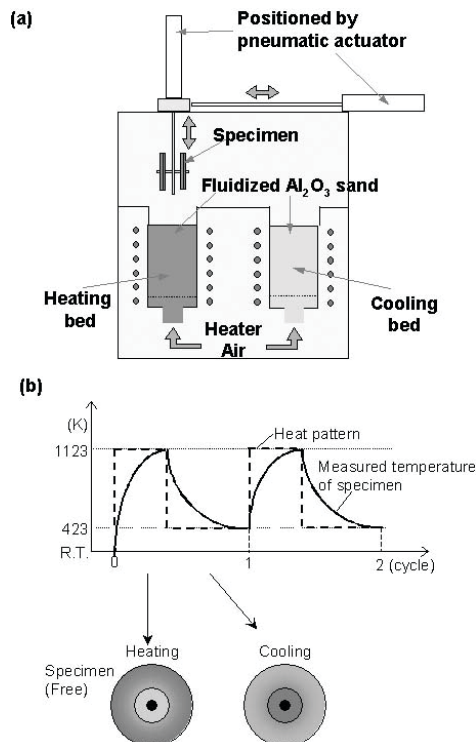


Figure 4 Experimental apparatus and conditions for thermal fatigue test. (a) Experimental machine (JIS Z 2278) (b) Conditions for thermal fatigue test.

Fluidized bed type thermal fatigue test - Self-restrictive type thermal fatigue tests using two fluidized bed furnaces (high temperature chamber and low temperature chamber) were performed according to JIS Z 2278^[7]. Figure 3(a) shows the form of a test piece and Figure 4 shows an overview of the testing equipment and the heat pattern which consists of immersion in the low temperature chamber at 423 K for 240 sec and the high temperature chamber at a specified temperature between 1073 and 1273 K for 180 sec. Consequently, the test piece was evaluated for its appearance, total crack length and dimensional changes against the number of cycles it has undergone.

Axial load type thermal fatigue test - A solid rod test piece shown in Figure 3(b) was used for the test. Unique axis hydraulic servo type fatigue equipment with an induction heater furnace shown in Figure 5(a) was used. The heat pattern and schematic deformation images during the thermal fatigue test are shown in Figure 5(b). The testing conditions employed were as follows: lower temperature: 423 K, upper temperature: 1173 K, heating time: 240 sec, holding time: 60 sec and cooling time: 510 sec. A strain waveform was obtained under the fully constrained condition in which the specific gauge length marked points never change their positions during a test. The fatigue life was defined either as the number of cycles at which the maximum tensile stress has reduced to 75% of the maximum tensile load at the second cycle or the number of cycles at which the test piece has become no longer measurable due to huge deformation or failure.

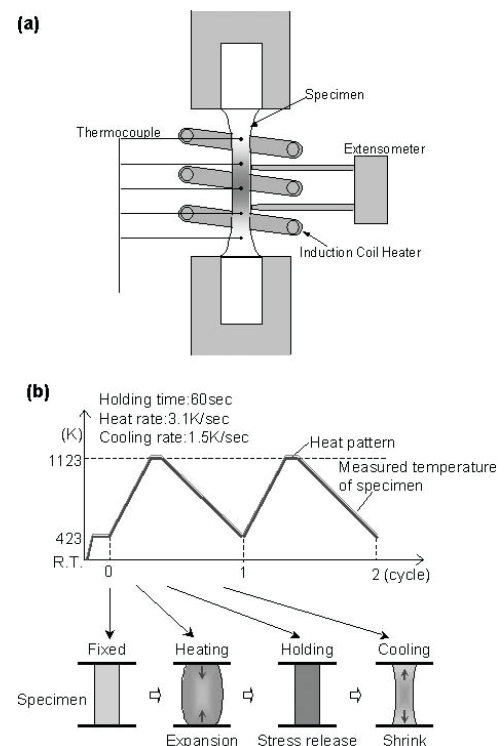


Figure 5 Experimental apparatus and conditions for thermal fatigue test. (a) Experimental machine. (b) Conditions for thermal fatigue test.