

Cylinder Head Gasket for High Combustion Pressure Diesel Engines

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ABSTRACT

The pressure of the combustion gas in a diesel engine is higher than that in a gasoline engine, so the cylinder head gasket that seals the combustion chamber is exposed to a severe environment. The sealability of the gaskets is affected not only by the gasket specifications, but also by the cylinder head, cylinder block, and the head bolts that clamp them. Consequently, in order to improve the performance of these gaskets, it is essential to enhance their material characteristics. Because the necessary characteristics of a gasket material are high strength and high fatigue strength, methods of realizing these enhancements were studied, and a new material was developed. It was confirmed that a gasket made using the newly developed material withstood high combustion pressure, and the gasket was used in a high performance diesel engine.

INTRODUCTION

In recent years, there are increasingly strong demands to reduce CO₂ exhaust emissions, which are a cause of global warming, in order to mitigate global warming. Enhancing fuel economy is an effective method of reducing CO₂ emissions from automobiles. There is an increasing tendency to use diesel vehicles, which have good fuel economy, mainly in Europe.

Because a diesel engine uses self ignition, the pressure of the combustion gas is higher than that of a gasoline engine. Consequently, the cylinder head gasket that seals the combustion chamber must have high sealing performance. As shown in Fig. 1, a head gasket generally consists of several metal plates, each of which have a thickness of about 0.2 mm and whose surfaces are coated with a rubber material having a thickness of several tens of microns. The head gasket performs its sealing function by utilizing the load reaction force of the beads that are formed into an angular shape, so the bead plate material must have high strength. Also, the cylinder head lifts due to the combustion pressure, and the beads follow this motion. Because repetitive stress is generated, high fatigue strength is required.

In order to meet these requirements, a new material aimed at achieving high strength through an aging treatment, and increased fatigue strength through use of a nitrogen absorption grain refinement process, was developed⁽¹⁾. A gasket was fabricated using this new material, and was used in a high combustion pressure diesel engine, thus contributing to higher engine output.

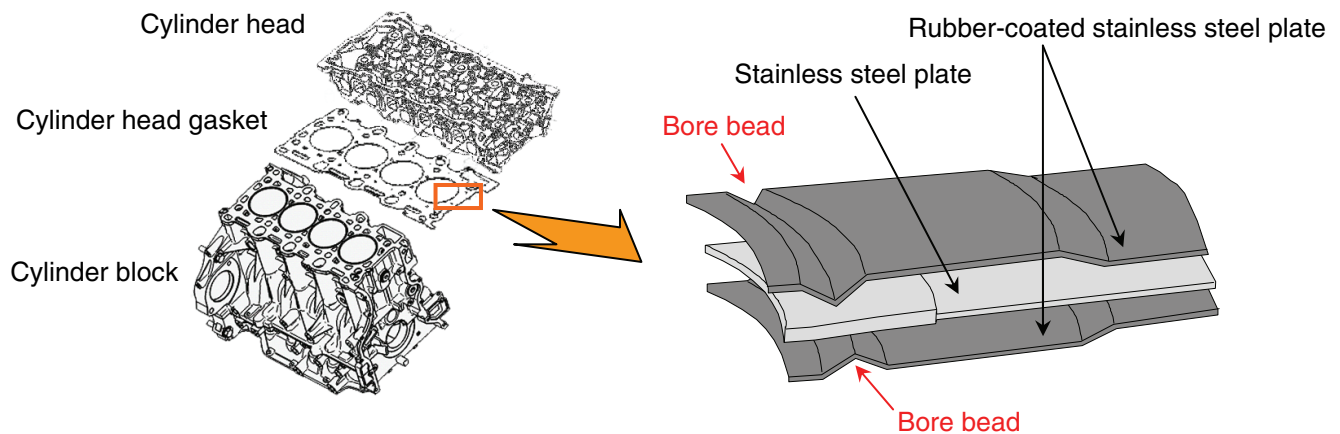


Fig. 1 Illustration of cylinder head gasket

1. INCREASED STRENGTH THROUGH LOW-TEMPERATURE AGING TREATMENT

1.1. Enhancing the Sealability by Utilizing a Rubber Heating Process

In order to prevent leakage from minute flaws existing in the seal surface, the surface of the gasket is coated with rubber material. NBR type or FKM type material is used as the rubber material. In order to increase the strength of these rubber materials, it is essential to carry out heating vulcanization of the rubber at a temperature of about 200°C. Materials for making springs are often heat-treated to increase their strength. In the case of SUS301 type of stainless steel, which is used mainly as a gasket material, rapid aging treatment is often performed at a temperature of about 400°C. Because this temperature is higher than the vulcanization temperature of the rubber material, it was previously necessary to perform aging treatment and vulcanization in separate processes.

In this research, stainless steel with increased strength resulting from low-temperature aging utilizing the heating vulcanization process for the rubber material was developed, aiming at enhancing the gasket characteristics without adding a new process.

1.2. Method of Low-temperature Aging

The methods of increasing strength are solution hardening, precipitation hardening, work hardening, and transformation hardening. The main material used as a head gasket material is SUS301 type of stainless steel, which utilizes transformation hardening. Accordingly, a study of adding precipitation hardening through low-temperature aging to this SUS301 type of stainless steel in order to realize even higher strength was carried out.

Because SUS301 type of stainless steel is metastable austenite, it changes to a martensite structure as a result of cold working. Regarding the interstitial solid element, the solution amount was large for an austenite structure in which the spaces in the crystal lattice were large, and was small for a martensite structure in which the spaces were small. Accordingly, it was decided to increase the strength of the stainless steel by utilizing this structural change, and the difference in the amount of solution. Low-temperature aging was carried out to promote precipitation of the interstitial solid elements that are supersaturated in the martensite structure.

Generally, carbon (C) and nitrogen (N) are the interstitial solid elements present in a metal, but N was selected in this research because the use of C would cause a chromium-depletion (Cr-depletion) layer to be formed along with the precipitation of the compound Cr_{23}C_6 , reducing the required corrosion resistance of the stainless steel.

1.3. Results of Confirming the Effectiveness of Nitrogen-added Stainless Steel

Figure 2 shows the results of a tensile strength test performed on a material consisting of SUS301L type of stainless steel to which 0.13% of nitrogen was added, after it had been cold-rolled and then aged for 10 minutes at each temperature. It shows the features whereby the strength of SUS301L increases from about 250°C, and saturates at about 400°C. The strength of the newly developed material increased by approximately 130 MPa as a result of low-temperature aging at a temperature of about 200°C, which had been studied as the vulcanization condition for the rubber material. The increase in strength more or less saturated at 250°C. The addition of nitrogen enabled aging treatment to be carried out at low temperatures. The

residue of the parent phase was found to be Cr_2N as a result of electron beam diffraction and EDX analysis. As shown in the TEM photograph of Fig. 3, the nitrogen, in a supersaturated condition in the martensite, is considered to have formed a compound with the Cr in the steel.

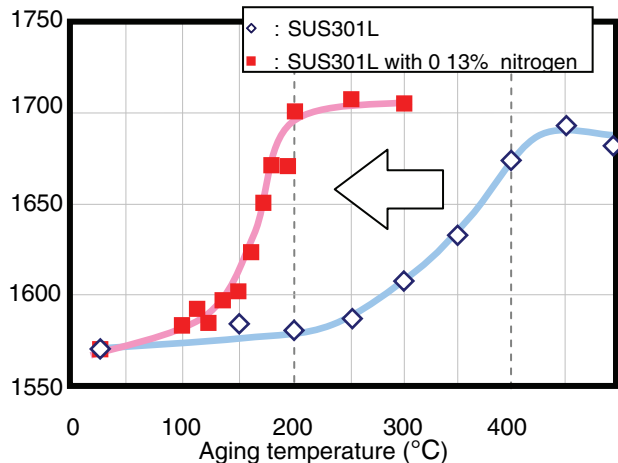


Fig. 2 Relationship between tensile strength and aging temperature

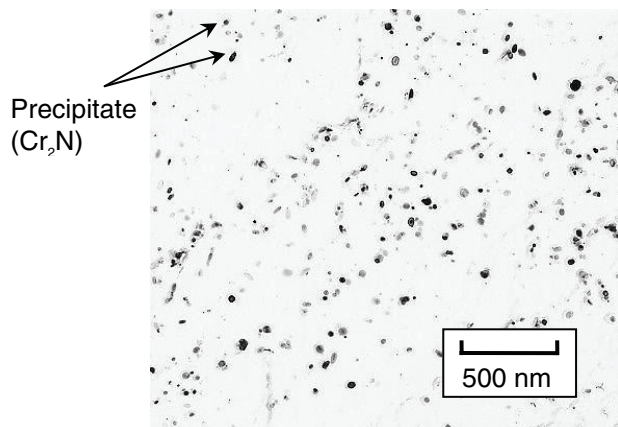


Fig. 3 TEM image of SUS301L with added nitrogen after aging treatment

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2. INCREASING FATIGUE STRENGTH

2.1. Study of Refinement of Grains

Generally, the higher the strength of a material, the higher its fatigue strength tends to be. However, in the case of a gasket, work stress, which occurs when the beads are press-formed, causes microcracks to appear at the grain boundary, leading to damage. The higher the notch sensitivity in the high strength material, the lower is the fatigue strength of the finished gasket. Consequently, grain refining and the realization of high formability, which suppress microcracks, are extremely effective in increasing the fatigue strength⁽²⁾, so a refining method was studied.

The refining method for SUS301 type of stainless steel is a method that utilizes the fact that when a work-induced martensite structure is heated, it reverse-transforms to an austenite structure, and recrystallizes⁽³⁾⁻⁽⁵⁾. This method is already being used as a refining method for NAR-301L HS1, which is used for mass production as a gasket material, and realizes an average grain diameter of 2 μm or less. In addition to this method, further refining through the utilization of the pinning effect due to deposits was the objective of this research. Generally, to ensure that stainless steel maintains a high degree of surface luster, bright annealing in a non-oxygenated atmosphere is used. Also, a mixture of hydrogen and nitrogen is widely used as the atmosphere gas. Consequently, nitrogen absorption is also being widely studied^{(6),(7)}. In this research, it was decided to utilize this technology.