NIOBIUM IN HEAT RESISTING CAST STEEL AUTO PARTS

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Abstract

The Casting Technology Research Laboratory at Hitachi Metals Ltd. developed a heat-resisting cast steel specifically directed at the automotive engine's exhaust systems. The new steel, HERCUNETE-S A3N, is an austenite cast steel having the chemical composition of 20%Cr-10%Ni-3%W-2%Nb was found to have the highest strength at over 600°C and exhibited the highest oxidation resistance at 900°C. Additionally, it was found to have a high thermal fatigue strength greater than Niresist D5S of an austenite cast iron structure. Due to the excellent properties at such elevated temperatures typical for exhaust gases, this developed cast steel grade was applied for exhaust manifold and turbine housings.

Introduction

A worldwide campaign for the protection of global environment is slowly, but powerfully evolving. Corresponding to this campaign, high efficiency, high performance and low emission automobile engines have been and are being developed. The result of such developments is the generation of higher exhaust gas temperatures. Consequently, existing exhaust manifolds and turbine housings develop many problems under these severe conditions, such as oxidation, thermal deformation or thermal cracks. Therefore, there is a drive within the industry to develop novel materials for exhaust components that are able to endure such high temperatures.

Figure 1 illustrates typical performance temperature ranges for the existing materials grades that are applied. As shown, the materials have developed from traditional gray iron to ductile iron, to high silicon ductile iron to the Niresist grade which is capable of withstanding temperatures around 800°C. However, it must be noted that the exhaust gas temperature reached on a high performance engine can reach up to 1000°C (1832° F). Therefore to meet the performance demands of modern engines the Casting Technology Research Laboratory at Hatachi Metals Ltd. developed a heat-resisting cast steel called HERCUNITE-S A3N.

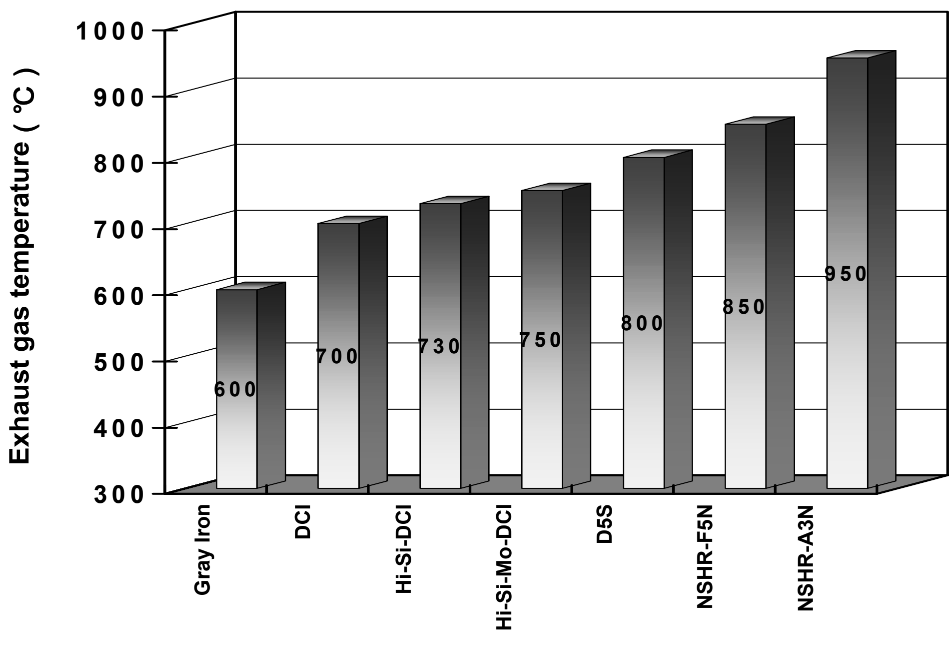

Figure 1: The development of heat resistance materials for high temperature exhaust gas systems.

Properties of New Heat Resisting Steel "NSHR"

Chemical Composition

The chemical composition of A3N and other comparison materials are shown in Table I. The newly developed A3N material is an austenitic cast steel which includes 20% chromium, 10% nickel, 3% tungsten and 2% niobium. A3N has a mixed structure of NbC networks, lightly modified colonies of carbides ($M_{23}C_6$) to strength the austenite matrix.

Proof Stress

The proof stress of each material at elevated temperatures is given in Figure 2. The proof stress has a direct effect on the anti-deformation property at temperature. These were measured by test pieces machined from Y-shaped cast blocks and these properties were measured in an muffle-type furnace at atmospheric pressure.

The Niresist D5S exhibited the highest strength. It was observed that the novel F5N (ferritic matrix) material gave a much higher strength than the D5S at a lower temperature region because of the existence of pearlitic colonies and that the matrix reinforced by the tungsten addition. The A3N demonstrated the largest strength among these materials at over 600°C.

Table I Typical chemical composition of NAHR-A3N and other materials

Comp.	C	Si	Mn	S	Cr	Ni	W	Mo	Nb	Fe
A3N	0.45	0.5	1.0	0.15	20.0	10.0	3.0	–	2.0	bal.
F5N	0.40	0.5	0.4	0.01	18.0	1.7	2.0	–	2.0	bal.
D5S	1.85	5.0	0.5	–	1.8	34.5	–	–	Mg	bal.
HiSiMo DCI	3.10	3.95	0.2	–	–	–	–	0.55	Mg	bal.

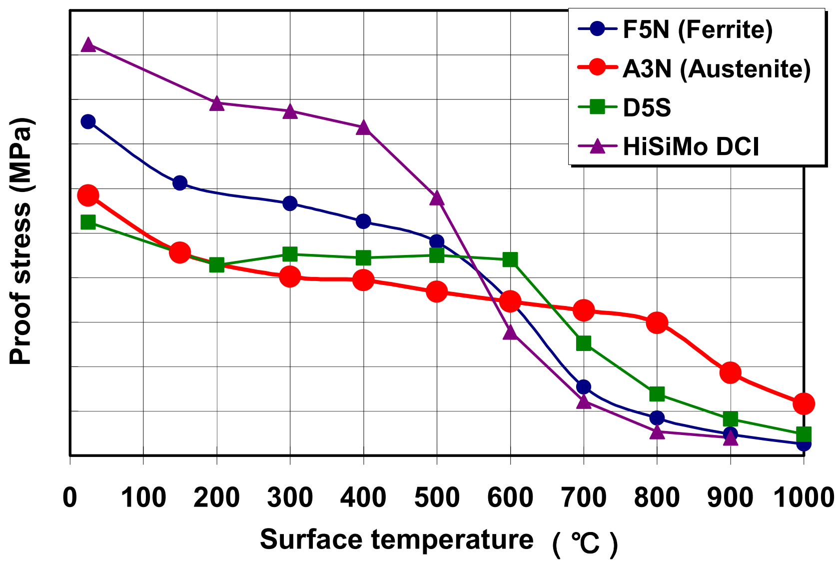

Figure 2: The proof stress (MPa) at temperature of the material given in Table I.

Coefficient of Thermal Expansion

The coefficients of thermal expansion of each material are shown in Figure 3. This value has an effect on the thermal deformation and the thermal cracks. For the tests conducted, the F5N material showed lower values over 200℃(418° F) than any other of the tested materials.

The A3N has a larger thermal expansion ratio because it is an austenitic material. Nevetheless, it also has a large proof stress, so it is able to endure the thermal stresses which occur by its larger thermal expansion ratio. Otherwise, D5S has is seen to posses a large coefficient of thermal expansion similar to A3N, but as it doesn't have a large proof stress, it is limited by its own thermal stress. Therefore it is necessary for these exhaust components to be design carefully.

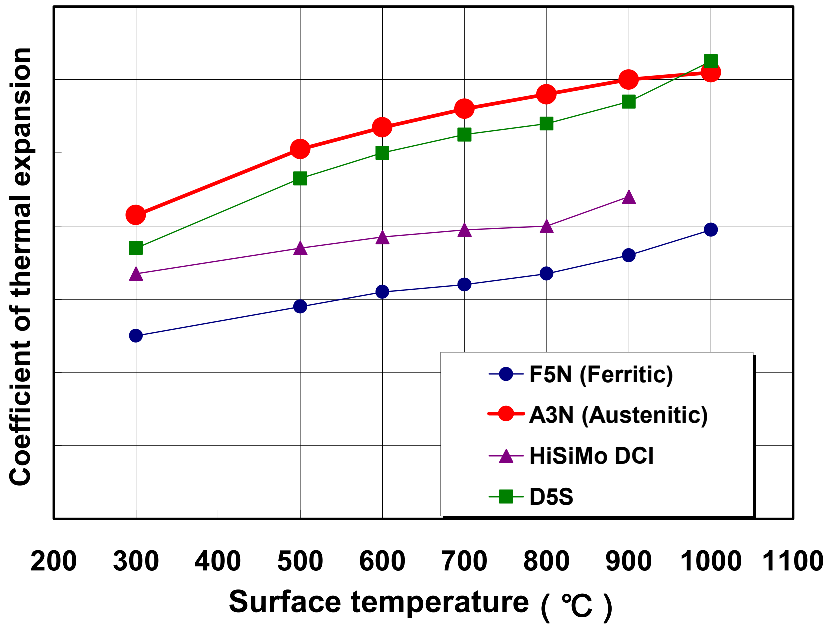

Figure3: Coefficient of thermal expansion of the materials given in Table I.

Coefficient of Thermal Conductivity

The coefficient of thermal conductivity of each tested material is given in Figure 4. As a temperature gradient will cause thermal deformation of exhaust parts, a lower coefficient of thermal conductivity becomes important the higher the temperature gradients as severe thermal stresses occur within the component.

The exhaust materials and the turbine housings, which is in contact with the engine coolant (i.e. cylinder head and center bearing housing of turbo charger) demands a material, which has a high thermal conductivity.

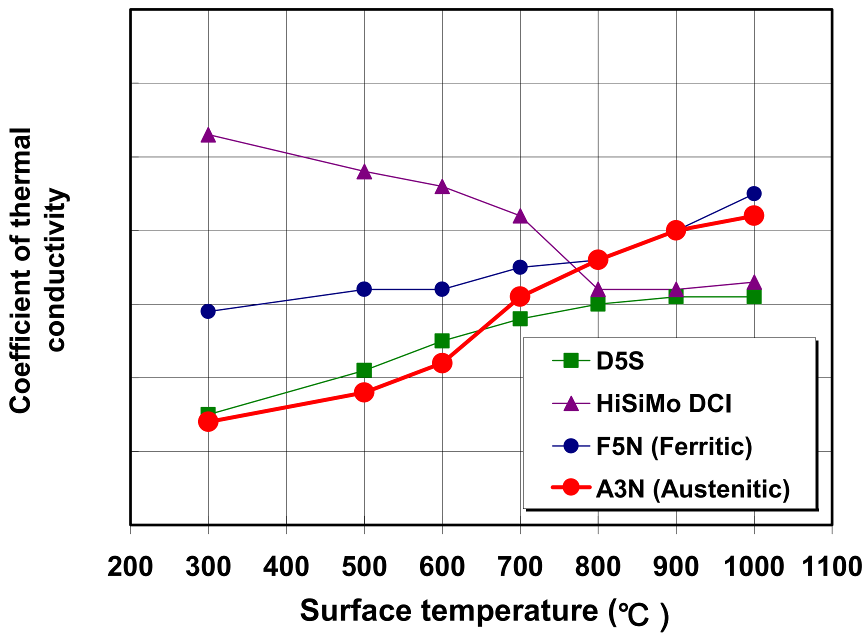

Figure 4: Coefficient of thermal conductivity of the materials given in Table I.

<u>Oxidation Resistance</u>

Figure 5 shows the results of the reduction in weight of each material under oxidation conditions of 900℃(1678° F)×200 hours in the atmosphere. This value has an effect on the anti-crack property.

As observed from the figure, the oxidation resistance of A3N is nearly twice that of Niresist D5S.

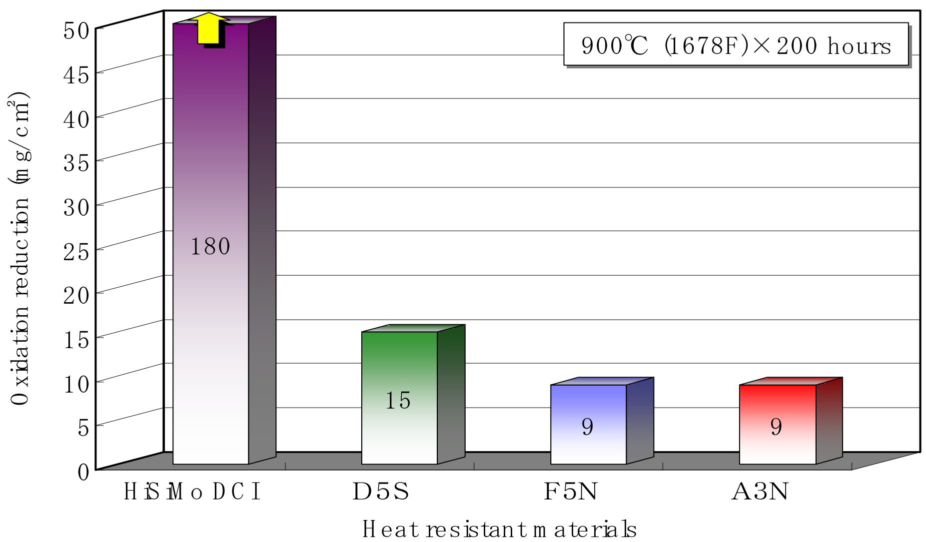

Figure 5: Comparison of oxidation reduction of each tested material as given in Table I.

Thermal Fatigue Properties

Figure 6 shows the results of a thermal fatigue life of each material by a Coffin-typed thermal fatigue testing apparatus. Considering a mechanism of crack origination, temperatures and thermal stresses can be regarded as "out of phase". The A3N was found to be remarkably superior to the conventional materials and it is nearly twice as good as the Niresist D5S.

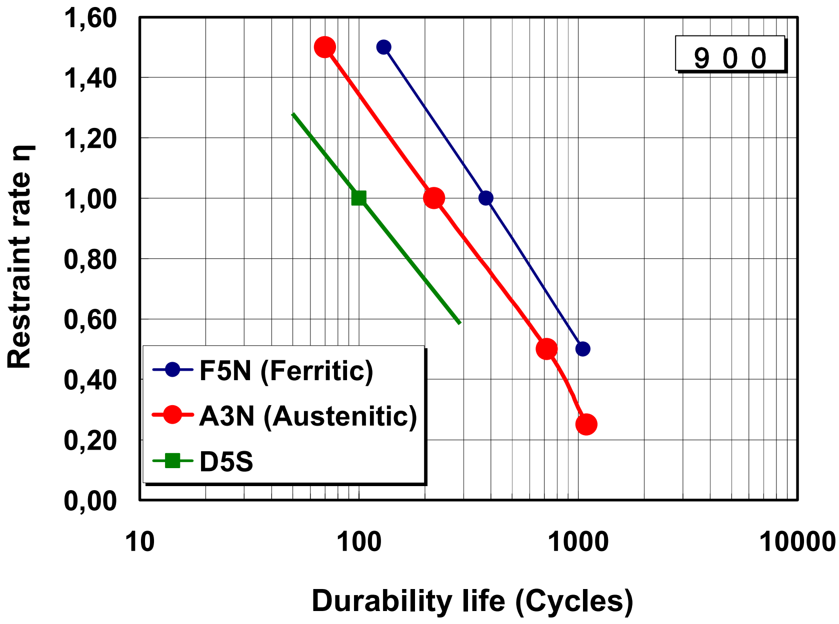

Figure 6: Thermal fatigue properties of 3 of the material tested at 900°C.

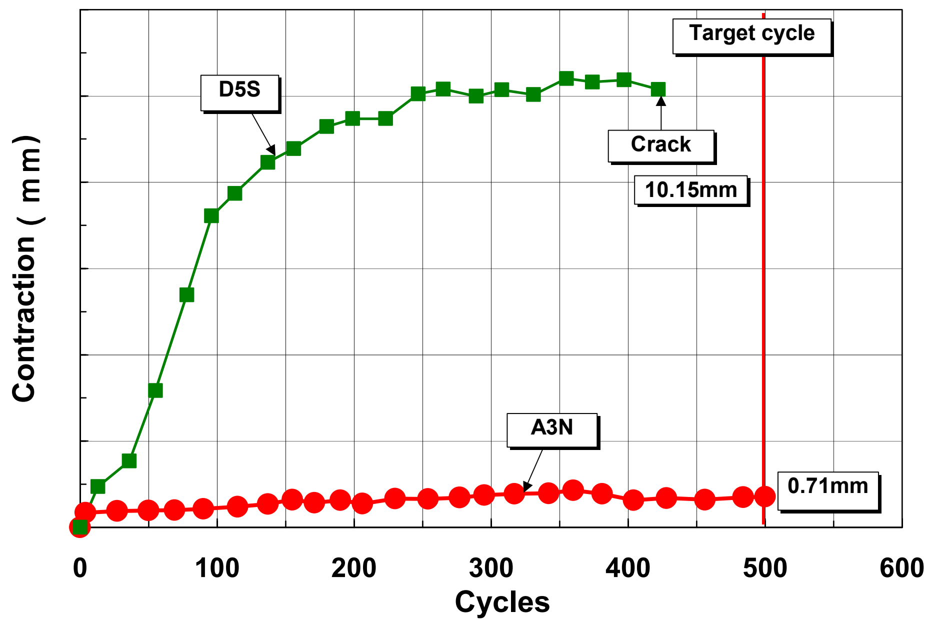

Figure 7: Difference of contractions of the exhaust manifolds made of D5S and A3N during the durability test at 900°C (1678° F).

Contraction of A3N Compared with Other Material

Figure 7 shows the difference of contractions of the exhaust manifolds made of D5S and A3N during the durability test at 900°C (1678° F). It shows that the exhaust manifold that is made of D5S generates a large contraction, which in turn initiates cracks on the surface after approximately 430 cycles. In contrast the manifold made of A3N shows only small contractions the test conditions and no other effects were observed.

The austenitic steel cast has a larger proof stress than the Niresist D5S and also has no spheroidised graphite particles. Therefore, it is good for preventing a thermal deformation and thermal cracks. This phenomenon causes the different of the strength of matrix. Furthermore, an austenitic matrix has a larger proof stress and steady state creep rate than a ferritic matrix. So it is excellent in preventing thermal deformation.

(a) In-line 4 cylinders engine

(b) Turbine housing

Figure 8: Applications for the developed material.

Applications

Figure 8 shows applications for the novel material A3N. As mentioned in above, the A3N is best suited for stability in performance in proof stress at elevated temperatures. As a result is can be applied not only for exhaust manifolds but also turbine housings. Figure 8(a) is an exhaust manifold for a V-type 10 cylinder petrol engine which is typically used in USA, and figure 8(b) is a turbine housing for a turbocharged engine which is typically used in Europe.

Conclusions

(1) The novel austenitic heat resisting cast steel (A3N) has been developed.

(2) The thermal fatigue properties of the A3N is nearly twice that of the Niresist D5S.

(3) The oxidation resistance of the A3N is eight times that of Niresist D5S.

(4) The thermal durability of the A3N is an improvement on the Niresist D5S.