Low Alloy Steel for Fracture Splitting Connecting Rod

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To reduce vanadium content in the steel for fracture splitting connecting rods, the effect of titanium addition on the splitting property was investigated. The results indicate that Ti addition effectively reduces the impact value of the steel. This is considered to be attributable to the decrease in the volume fraction of ferrite and in the precipitation strengthening of the ferrite. Furthermore, Ti was also found to have no adverse effect on machinability. Based on these results, a new steel was developed for fracture splitting connecting rods.

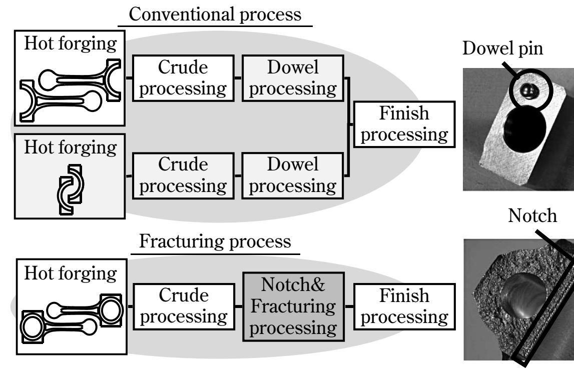

Fig. 1 Manufacturing process of connecting rods

Introduction

Among the characteristics required for automobiles, "low environmental burden" and "safety" are two key features gaining increasing recognition. The environment, in particular, is receiving much public attention, and automakers are actively moving forward to develop low-emission and fuel-efficient cars[1), 2)].

Automobiles must be manufactured at a low cost while achieving the above objectives. To reduce the cost, low alloy steel is being pursued, as is a simplified manufacturing process. With this background, a method of production according to the fracture splitting process was developed to reduce the cost of manufacturing connecting rods, which are automobile engine parts[3)]. The conventional process for making a connecting rod includes forging and rough-machining the rod portion and cap portion separately, providing these portions with dowels and coupling them before finishing. On the other hand, according to the fracture splitting process, the rod and cap portions are forged and rough-machined as a unified body and notches are machined on the body along a plane, which later becomes the coupling surface. In the subsequent step, the forged body is fractured along these notches to split the rod and cap portions, and finish machining is performed on these split portions (**Fig. 1**). This production method improves the material yield of the forged body and eliminates the need for processing cap portions, dowel pins and the holes. Since the fracture splitting method was implemented in the 1990s, it has prevailed in Europe and US, and an increasing number of Japanese manufacturers have introduced this method[3) - 6)].

Steel for fracture splitting connecting rod must be split with minimum deformation (fracture splittability), in addition to possessing the characteristics required for conventional steel used in connecting rods. In Europe, a steel, C70S6, according to the DIN standards, is widely used. This steel has a microstructure that is almost entirely occupied by pearlite to ensure fracture splittability. Kobe Steel also developed a steel for fracture splitting connecting rod with high-strength. The steel ensures fracture splittability by the increased addition of P and V, as well as spheroidized MnS[7)].

To avoid the risk of relying on scarce resources, Kobe Steel pursued a technique for improving the fracture splittability with less addition of V and has newly developed a steel for fracture splitting connecting rod based on newly acquired knowledge. This paper outlines that development.

1. Study on alternative means for low alloying

Although C70S6 steel contains no alloying element with a high availability risk, it suffers from a lack of machinability because it contains a large amount of hard cementite. On the other hand, non-heat-treatment steel, consisting of ferrite and pearlite, has fewer problems with machinability; however, the toughness of its proeutectoid ferrite (hereinafter simply referred to as "ferrite") must be reduced to improve its fracture splittability. This is clear from the fact that reduced impact strength improves fracture splittability[7)]. A method is being developed to reduce its impact resistance by adding V and/or P to increase the strength and thus to embrittle the ferrite.

Because Vanadium is produced by a limited number of countries and is a scarce resource with availability risk[8], an alternative element has been sought. Thus, Kobe Steel has focused on Titanium, which is considered to have a large output with less risk of unavailability, and which forms carbide as in the case of V. The company conducted a study on the effect of Ti addition on impact resistance and machinability to determine the feasibility of substituting Ti for V.

2. Experimental procedure

2.1 Materials tested

Table 1 shows the chemical compositions of the materials tested. Four types of steels were tested, i.e., two types of steels (Steel A and Steel B), with or without Ti, to study the effect of Ti, a steel (Steel C) equivalent to C70S6 as a reference for evaluating fracture splittability, and a steel (Steel D), equivalent to the conventional steel used for connecting rod, as a reference for evaluating machinability. The steels were melted in a laboratory scale vacuum melting furnace, and hot forged at 1,200℃ into a predetermined shape before the testing.

2.2 Impact test

To study the effect of Ti on impact strength, Steel A and Steel B were subjected to a Charpy impact test. A hot forged cylinder having a diameter of ϕ30mm was hot pressed in a diametrical direction to produce a plate having a thickness of 15mm, from which a U-notched specimen was prepared.

2.3 Machinability test

Drill life was evaluated to study the machinability. A hot forged cylinder having a diameter of ϕ80mm was provided as a work material whose cross-section was subjected to drilling for drill life evaluation. The tool used was a high-speed steel drill with a diameter of ϕ10mm. The test was conducted under dry conditions with a feed rate of 0.21mm per revolution. The total cutting length until the drill broke was taken as the drill life.

Table 1 Chemical compositions of samples (mass%)

Sample	C	Si	Mn	P	S	Cr	V	Ti
Steel A	0.38	0.25	1.07	0.051	0.050	0.18	0.170	0.051
Steel B	0.38	0.24	1.08	0.049	0.050	0.18	0.160	—
Steel C	0.70	0.23	0.54	0.011	0.058	0.11	—	—
Steel D	0.41	0.26	1.06	0.019	0.060	0.23	0.099	—

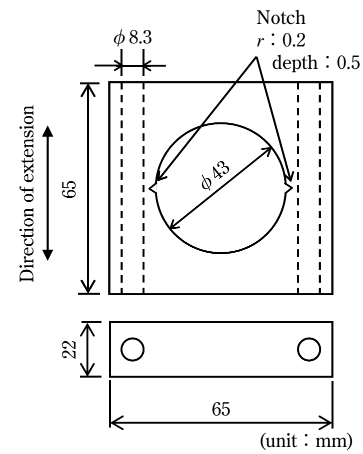

Fig. 2 Fracture splitting test piece

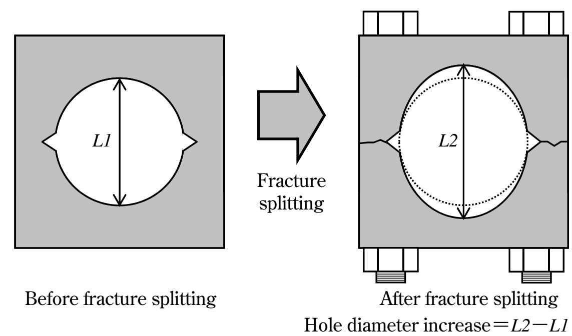

Fig. 3 Measuring method of hole diameter increase

2.4 Fracture splitting test

The fracture splittability was evaluated by a fracture splitting test. A hot forged round bar with a diameter of ϕ65mm was hot pressed in a diametrical direction to produce a plate having a thickness of 25mm. The plate was machined into a fracture splitting specimen as shown in **Fig. 2**. The notches were provided in a direction vertical to the forging direction such that the fracture split would occur at positions that simulate actual connecting rods. The fracture splittability was evaluated by the change in the hole diameters before and after fracture splitting. In other words, as shown in **Fig. 3**, the hole diameter was measured before the fracture splitting and was measured again after the split parts were fastened by bolts. The difference in the hole diameter was taken as an index of fracture splittability.

3. Experimental results and discussions

3.1 Impact test

Fig. 4 shows the results of the Charpy impact tests. It has turned out that the addition of Ti decreases the impact resistance significantly. The fracture surfaces and microstructures of impact

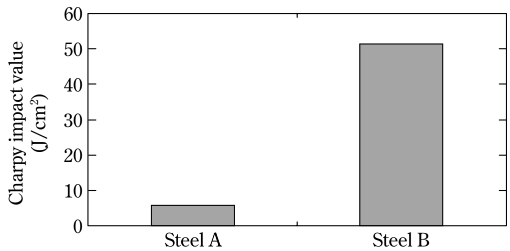

Fig. 4 Result of Charpy impact tests

specimens Steel A and Steel B were observed in detail to elucidate the phenomena that occurred during the impact test.

3.1.1 Fracture surface observation

Fig. 5 shows the SEM micrographs of fracture surfaces. Steel A exhibits cleavage throughout almost the entire surface without any of the dimpling that is a feature of ductile fracture. The partially observed grain boundaries indicate that the fracture, to put it more exactly, is caused by quasi-cleavage. Steel B, on the other hand, exhibits dimples throughout almost the entire surface of the specimen at the notch bottom where the initial crack was introduced. It should be noted that the cleavage fracture surface is located more than about 300μm inside the fracture surface.

This indicates that the decrease in impact resistance brought about by the addition of Ti is attributable to the suppression of ductile fracture accompanying dimples. These dimples are generated by the plastic deformation of matrix surrounding inclusions, and in a ferrite-pearlite structure, the plastic deformation is mainly governed by ferrite[9]. Thus it is highly possible that the addition of Ti serves to embrittle the ferrite.

3.1.2 Microstructure

Microstructures were observed to study the change in the ferrite. **Fig. 6** shows the results of the study. The addition of Ti has turned out to decrease the ferrite fraction from 29% to 20%, while increasing the hardness from 272.0HV to 294.7HV. The decreased ferrite fraction raises the ductile-brittle transition temperature[9], lowers the upper shelf energy[10] and lowers the impact resistance value. These effects are considered to be the cause of the lowered impact value.

Now, a detailed study was carried out to elucidate the cause of the ferrite fraction's being decreased by the addition of Ti. Continuous cooling transformation (CCT) diagrams were prepared to study the transformation behaviors. The heating temperature was set to 1,200℃ to simulate the behavior during hot forging. The results are shown in **Fig. 7**. The results indicate that the addition of Ti delays the initiation of diffusion transformation (ferrite transformation), shifting the curves toward longer times and lower temperatures.

The following discusses the reason why the Ti addition delays the initiation of ferrite transformation.

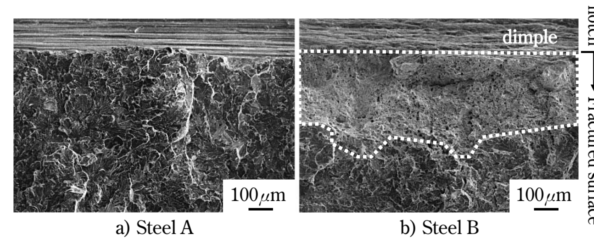

Fig. 5 SEM images of fractured surface

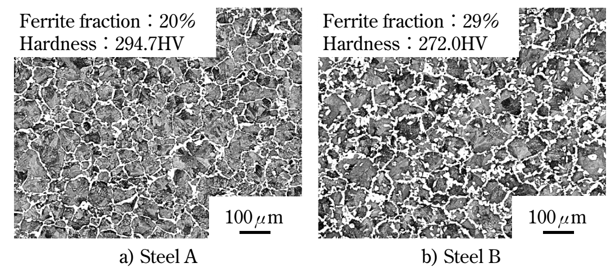

Fig. 6 Microstructures and hardness of Steel A and B

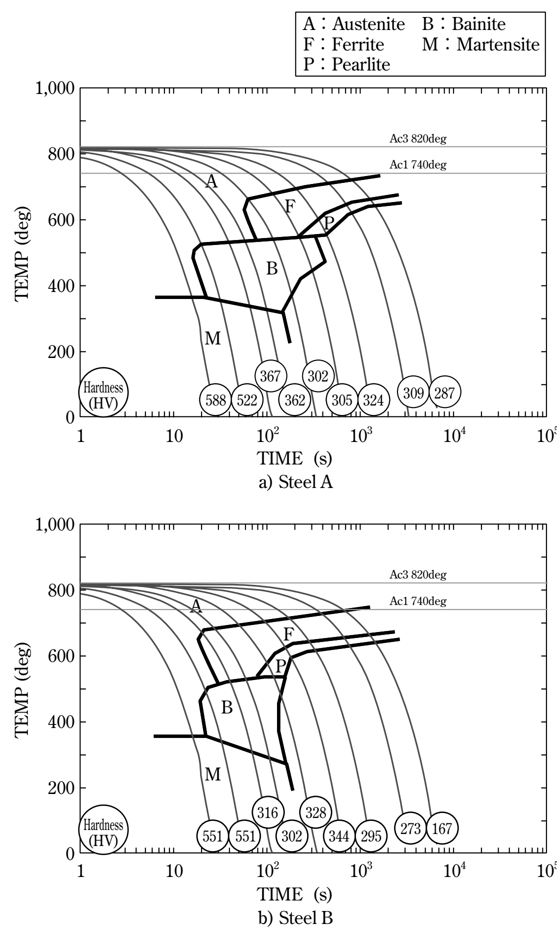

Fig. 7 Continuous cooling transformation diagram

Firstly, Ti is an element having a strong affinity with C, forming carbide. Another carbide forming element, V, has been known to decrease the diffusion rate of C[11]. Thus, Ti is assumed to decrease the diffusion rate of C, as in the case of V. The decreased diffusion rate is considered to suppress diffusion transformations such as ferrite transformation and pearlite transformation.

Next, a detailed study was conducted on the increase of hardness. The hardness increase is attributable both to the precipitation hardening effect of TiC and the decrease in the ferrite fraction. To verify the effect of the ferrite fraction on the hardness change, a mixing rule was adapted for hardness. The mixing rule for hardness is given by the following relationship[12]:

$$HV = f_\alpha^{1/3} HV_\alpha + (1 - f_\alpha^{1/3}) HV_p \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

in which HV represents overall hardness, f_α represents the ferrite fraction, HV_α represents ferrite hardness and HV_p represents pearlite hardness.

The effect of the ferrite fraction was calculated for the ferrite fractions shown in Fig. 6, assuming HV_α= 235 and HV_p=295. According to the calculation, a 9 percent decrease in ferrite fraction increases the hardness by about 5HV. Thus, in the total hardness increment of about 23HV, shown in Fig. 6, approximately 18HV is attributable to precipitation hardening by TiC. This precipitation hardening is considered to have caused the ferrite to harden and embrittle.

3.1.3 Embrittlement mechanisms by Ti addition

From the above, the following is proposed to be the mechanism of Ti addition decreasing the impact resistance.

The addition of Ti serves i) to decrease the ferrite fraction, raise the ductile-brittle transition temperature and lower the upper shelf energy; and ii) to cause precipitation hardening, to increase the strength of ferrite and to decrease the plastic deformability.

These effects cause cleavage fracture to occur while suppressing the ductile fracture that accompanies dimples, leading to reduced impact resistance. Particularly in this study, the ferrite fraction had a significant effect, which can be exploited in improving the fracture splittability by reducing the impact resistance value.

3.2 Machinability test

Fig. 8 shows the results of the machinability test. The machinability of Steel C (C70S6 equivalent) was dramatically degraded, while Steel A, Steel B and Steel D exhibit almost equal tool lives, indicating no adverse effect of Ti addition on machinability. Steel D is the steel equivalent of conventional connecting rod.

3.3 Fracture splitting test

Based on the knowledge obtained in Sections 3.1 and 3.2, compositions were determined for low alloy steel for fracture splitting connecting rod. The low alloy steel has a strength (proof strength of about 600MPa) equivalent to that of the conventional connecting rod steel (Steel D). **Table 2** shows a sample composition of the newly developed steel. This steel contains Ti in about the same amount as in Steel A, in which the effect of Ti addition has been sufficiently confirmed. It also contains V in about the same amount as in Steel D to achieve the same level of strength. The newly developed steel contains V in an amount reduced by about 60% compared with the conventional steel made by Kobe Steel for fracture splitting connecting rod.

Fracture splitting tests were conducted on the five steels; i.e., Steels A-D and the newly developed steel. **Fig. 9** shows the test results. The newly

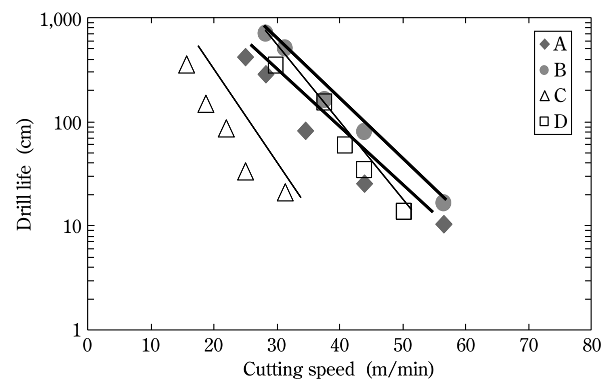

Fig. 8 Results of drill life test

Table 2 Chemical compositions of developed steel

(mass%)

Sample	C	Si	Mn	P	S	Cr	V	Ti
Developed steel	0.37	0.25	1.12	0.047	0.062	0.29	0.106	0.043

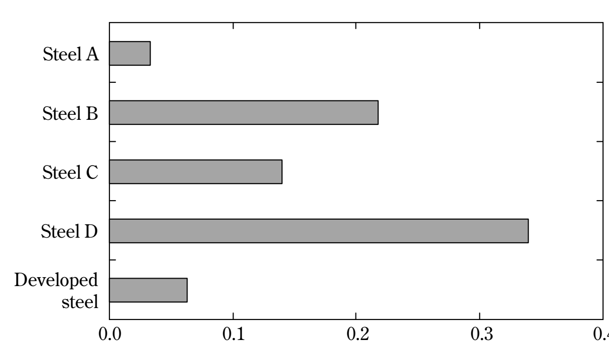

Fig. 9 Hole diameter increases

developed steel and Steel A, both containing Ti, exhibit a fracture splittability that significantly exceeds that of Steel B and Steel D without Ti addition and is better than that of Steel C, the C70S6 equivalent. The results confirm that the addition of Ti enables the improvement of fracture splittability with a decreased addition of V.

Conclusions

With the aim of developing a low alloy steel for fracture splitting connecting rod, a new technique was devised to improve the fracture splittability, in which Ti is substituted for V. It has turned out that the addition of Ti decreases the ferrite fraction, induces the precipitation hardening of the ferrite, facilitates cleavage fracture and reduces the impact resistance value. Furthermore, the Ti addition has been found to ensure favorable fracture splittability without sacrificing machinability. Based on the new knowledge, a new steel, containing much less V, was developed for fracture splitting connecting rods.

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