2015-32-0830
20159830
Published 11/17/2015

saeeng.saejournals.org

Development of Fracture-Split Connecting Rods Made of Titanium Alloy for Use on Supersport Motorcycles

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ABSTRACT

A connecting rod made of titanium alloy is effective for lower fuel consumption and higher power output comparing to a steel one because the titanium connecting rod enables to reduce the weight of both of reciprocating and rotating parts in an entire engine substantially. But up to now, it has been adopted only to expensive and small-lot production models because a material cost is high, a processing is difficult and a wear on a sliding area should be prevented. In order to adopt the titanium connecting rods into a more types of motorcycles, appropriate materials, processing methods and surface treatment were considered. Hot forging process was applied not only to reduce a machining volume but also to enhance a material strength and stiffness. And the fracture-splitting (FS) method for the big-end of the titanium connecting rod was put into a practical use. The brittle fractured surface of the big-end by FS method is useful for not only cost reduction but also ensuring the stiffness of the connecting rod compensating the low elastic modulus of titanium alloy comparing to that of ferrous alloys. In this study, the evaluation results of materials characteristics related to these processes and functional property of surface treatment is described. From these evaluations, the capabilities of FS titanium connecting rods were quantitatively shown. FS titanium connecting rods have been produced for the supersport motorcycle engines from November 2014.

CITATION: Kubota, T., Doi, K., Murakami, T., Kojima, Y. et al., "Development of Fracture-Split Connecting Rods Made of Titanium Alloy for Use on Supersport Motorcycles," *SAE Int. J. Engines* 9(1):2016.

INTRODUCTION

Titanium connecting rods (Figure 1) have a higher mass-to-fatigue-strength ratio than steel connecting rods and therefore they can be made lighter in order to satisfy the same durability. Reducing the mass reduces the inertial force during usage, thus higher power can be achieved by increasing engine revolution, and friction loss can be reduced by reducing the contact pressure of the sliding portion. Furthermore, besides making the connecting rod itself lighter in weight, a lighter connecting rod makes it possible to reduce the mass of the crankshaft, which must be balanced in relation to it, thus resulting in a significant contribution to reducing the overall weight of the motorcycle. The example of the motorcycle using titanium connecting rods is shown in figure 2. However, three issues exist for using titanium for connecting rods: The first is the high cost. In addition to the high cost of titanium as a material itself, hot forging and machining titanium is difficult, resulting in high production costs. Consequently, titanium connecting rods have only been used in certain high-end vehicles until now [1, 2, 3, 4, 5]. The second is titanium's low elastic modulus, which increases deformation in the bore of the big end during use and may lower reliability with regard to crankshaft seizure. The third is titanium's thermal conductivity, which is 30% or less that of steel. As a result, titanium is prone to both retaining sliding heat and reacting with other metals, causing adhesive wear.

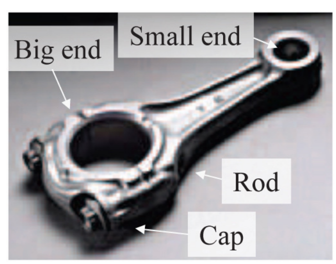

Figure 1. Titanium connecting rod.

Figure 2. Motorcycle.

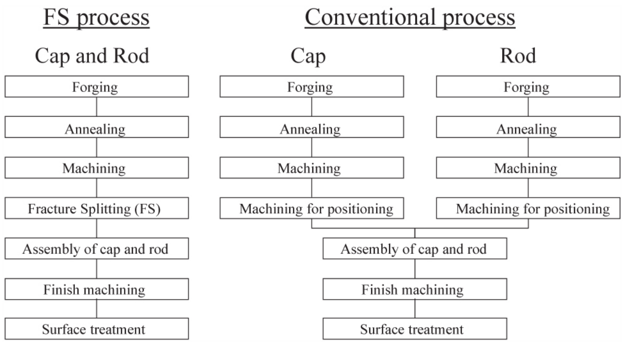

Figure 3. Fabrication process for FS connecting rods.

To overcome the first and second issues, application of the Fracture Splitting (hereinafter referred to as "FS") process [6,7] to titanium connecting rods was examined. In the FS process, the cap and rod (Figure 1) are hot-forged as one piece and then machined as one piece (Figure 3). The FS process is carried out during the machining process to make a brittle fracture between the cap and the rod. The cap and rod are then immediately assembled together utilizing the brittle fracture surfaces for positioning, and then finish-machined as one piece again. The FS process allows the hot-forging of the cap and rod as one piece, improving the percentage of material available and reducing the number of hot-forging steps compared to forging the cap and rod separately. Additionally, since the cap and rod are machined as one piece throughout all of the processes, the number of machining steps is significantly reduced. In this way, the aforementioned first issue, i.e., cost, can be resolved. Furthermore, the fact that the cap and rod are assembled on their brittle fracture surfaces makes it easier to reproduce a high level of roundness in form during processing after the crankshaft is assembled, and results in almost no shifting in the mating face during use, making it possible to reduce deformation in the bore of the big end [7]. This solves the aforementioned second issue, that is, reliability with regard to crankshaft seizure is improved. To prevent the third issue of adhesive wear, it has been routine with conventional titanium connecting rods to press-fit a copper bushing into the small end and apply a surface treatment, such as molybdenum spraying or dry coating, to the thrust portion of the big end. However, using a copper bushing increases the outer diameter of the small end, leading to an increase in mass, which reduces the benefit of using titanium. Furthermore, applying different surface treatments to the small end and big end increases production cost. Therefore, in this report, a surface treatment that can simultaneously satisfy the adhesive wear resistance requirements of the small end and big end was selected based on an examination of wear resistance, seizure resistance, and adhesion characteristics among the surface treatments commonly being carried out industrially to improve the wear resistance of titanium materials.

This report also examined hot-forging conditions from the standpoint of meeting the required levels of formability and strength. Hot forging also helps improve fatigue strength and toughness, which are important qualities for connecting rods. Although there have been several examples of applying hot forging to the production of titanium connecting rods [1,4,5], the processing difficulty in these examples can be expected to be higher than that for steel connecting rods. Therefore, to aid in estimating the degree of difficulty in hot forging of the targeted titanium material, hot workability was evaluated and compared to hot forging for conventional SCM420 steel material.

The objective of the study was to carry out the aforementioned evaluations in order to solve cost-related issues of titanium connecting rods, and improve their reliability so that they could be used in wider range of motorcycle models.

EXPERIMENTAL PROCEDURE

Material

In the examination, ASTM B348 Gr5 (hereinafter referred to as "Ti-6Al-4V"), which is widely used as a titanium material for connecting rods, and the α+β type titanium alloy (hereinafter referred to as "Ti-5Al-1Fe") which contains 5% aluminum and 1% iron, were both evaluated. The case hardening steel JIS SCM420 (hereafter referred to as "SCM420") was also prepared as a reference. In all tests, Ti-6Al-4V and Ti-5Al-1Fe were annealed at a temperature of 1,013 K for two hours before being used in the tests. SCM420 underwent carburizing, quenching and tempering to obtain a 550HV effective case hardness depth of 0.5 mm. Table 1 lists the materials that were evaluated and the heat treatments they were subjected to.

Table 1. Materials and heat treatments.

	Material	Heat treatment
Ti-6Al-4V	ASTM B348 Gr5 (Alpha-beta titanium alloy containing 6 mass% aluminum and 4 mass% vanadium.)	Annealing (1013K, 2hours)
Ti-5Al-1Fe	Alpha-beta titanium alloy containing 5 mass% aluminum and 1 mass% iron.	Annealing (1013K, 2hours)
SCM420	JIS SCM420H (Case hardening steel containing 1 mass% chromium and 0.2% molybdenum.)	Carburizing, quenching and tempering (Effective case depth 0.5mm, above 550HV)

Fatigue Strength Test

In developing and selecting materials and processing methods, fatigue strength, which has the greatest influence on connecting rod functionality, was evaluated. Figure 4 shows the test piece used for the fatigue strength test. The area to be tested has a notch shape with a 1.0 mm radius. An Ono-type rotary bending fatigue testing machine made by Shimadzu Corporation was used for the test, which was conducted at room temperature and a rotation speed of 60 rotations/sec. The test results are shown as the stress amplitude of the maximum stress at the bottom of the notch, with stress concentration taken into account. The calculated stress concentration factor was 1.78.

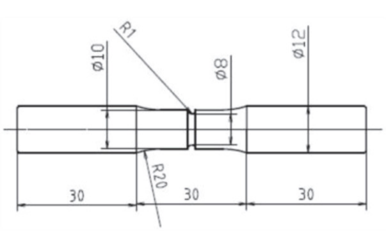

Figure 4. Rotating fatigue test piece.

FS Process Test

Use of the FS process allows more accurate positioning of the cap and rod when the connecting rod is being installed on the crankshaft and also improves the reproducibility of the roundness of the bore of the big end during finishing. To achieve these benefits, however, the fracture surfaces made by the FS process need to be brittle fracture surfaces. If the fracture surfaces are ductile, the positioning accuracy declines, worsening the amount of deviation from circular form [8]. When a Charpy impact test is performed using a JIS No. 3 test piece as an indicator of brittleness, for example, forged steel optimized for the FS process results in a value of 19-23 J/cm^2 [9], while Ti-6Al-4V results in a value of 39 J/cm^2 [10], suggesting that it will likely be difficult to achieve brittle fracture. Therefore, using a connecting rod itself as a test piece, brittle fracture conditions [8] were examined with changing temperature and strain rate as parameters.

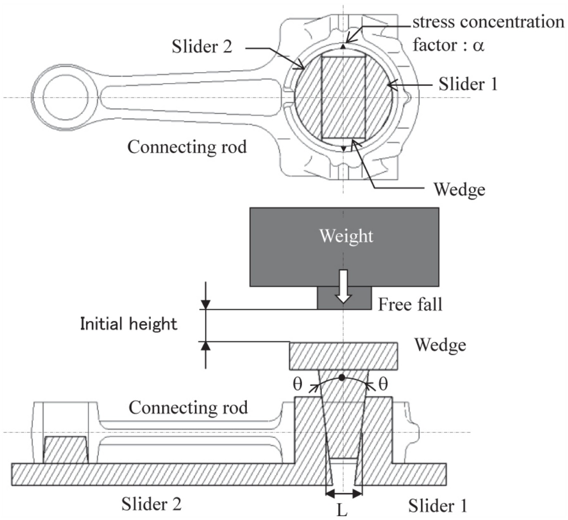

Figure 5. Connecting rod and FS jigs.

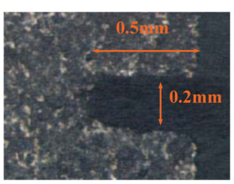

Figure 6. Shape and dimension of the groove.

The falling weight-type splitting machine shown in Figure 5 was used for the test. The big end of the test piece was fractured by applying the potential energy of the weight to the wedge, which in turn opened the slider in the test piece's axial direction. Electric discharge machining was used to create a groove for the purpose of crack initiation on the inner circumferential surface of the big end of the test piece. Figure 6 shows the shape of the groove. With this method, it is difficult to accurately measure the strain rate of the bottom of the groove cut for crack initiation. Therefore, the strain rate S was defined as shown in Equation (1).

$$S = \frac{2V_{wg}\tan\theta}{L}\alpha \tag{1}$$

Here, Vwg is the maximum velocity of the wedge; θ is the wedge angle; α is the stress concentration factor on the bottom of the crack initiation groove; and L is the distance between the working points of the slider (Figure 5).

As for the Ti-5Al-1Fe material, Charpy impact testing has not been performed until now. The impact values by JIS No. 3 test piece were evaluated and the results compared with those of other materials to use as reference in considering brittle fracturability.

Hot Workability Evaluation

To investigate the processing conditions for hot forging, high-temperature and high-speed deformation tests in the tensile and compressive directions were conducted using the Thermecmastor Z made by Fuji Electronic Industrial Co., Ltd. The test piece shown in Figure 7 was used for the tensile test. The effects of the testing temperature on the maximum tensile load and the reduction rate of a cross-sectional area were examined at a tensile speed of 400 mm/sec. For the reduction rate of a cross-sectional area, the amount of reduction in the fracture surface area measured before and after the test was divided by the cross-sectional area before the test to obtain a percentage value. The test piece shown in Figure 8 was used for the compressive test. With the goals of a deformation rate of 500 mm/sec. and a draft of 50%, the effects of the testing temperature were examined, i.e., the maximum compressive stress and the temperature increment quantity induced from the processing. The maximum compressive stress was expressed as nominal stress. For both tests, a testing temperature range of 673 K to 1,323 K was used for the titanium material and a range of 673 K to 1,473 K was used for the steel material.

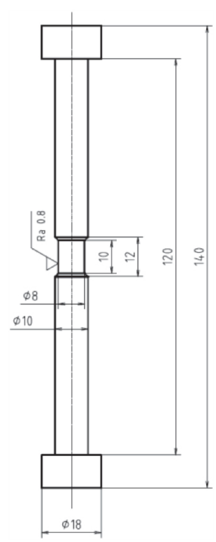

Figure 7. Tensile strength test piece.

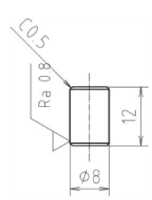

Figure 8. Compressive strength test piece.

Surface Treatment Selection

Evaluated Surface Treatments

Examples of surface treatments that have been industrially adopted as wear-resistant surface treatments for titanium materials include wet plating, diffusion treatment (oxygen diffusion and plasma carburizing), dry coating, and thermal spray [11]. Of these, the surface treatments described in Table 2 were selected for evaluation. The two friction/sliding tests described below were sequentially carried out to evaluate whether both the small end and big end could be simultaneously processed, wear resistance, seizure resistance and adhesion. With regard to sputtering CrN, two kinds of film where the indentation hardness is different was made by changing the flow rate of nitrogen gas. Besides the surface treatments described in Table 2, oxidation and DLC processing using hydrogenated amorphous carbon were also evaluated. However, both were eliminated from the list of candidates for the following reasons: (1) Oxidation could not produce a sufficient bore roundness as the final process because of the high processing temperature, and (2) the DLC process could not produce sufficient coating film hardness when applied to the bore. Note that Ti-5Al-1Fe was used as the base material for all surface treatments.

Table 2. Thickness and hardness of the surface treatments.

		Type of Film	Thickness um	Indentation hardness (Nano-indentation method) GPa
Plating		NiP	15.0	10.3
PVD	Sputtering	CrN (High hardness)	3-5	20.5
		CrN (Low hardness)	3-5	12.5
	Arc ion plating	CrN	3-5	24.6
		TiAlN	3-5	37.4

Reciprocating Slide Type Friction Test

To examine basic frictional abrasion characteristics, a reciprocating slide type friction test was conducted. The SRV tester made by Optimol Instruments Prüftechnik GmbH was used. In terms of the shape of the test piece, the upper-side pin had the shape of a truncated cylinder and the lower side had a plate shape. The two sides were made to have line contact and various types of surface treatments were applied to the plate side for evaluation. Carburized, quenched and tempered SCM420 was used for the pin side, with a surface hardness of 700 HV. On the plate side, the surface was polished before surface treatment application. For comparison purposes, an SCM420 plate was also prepared. Friction coefficient, wear resistance and seizure resistance were examined under the test conditions shown in Table 3. The indicated temperature was taken on the plate side. The friction coefficient was examined with engine oil dripping before friction tests to make the testing environment more similar to that of an actual motorcycle. For the wear resistance test, Super Marupasu 10, a machine oil made by JX Nippon Oil & Energy containing no extreme pressure additives, was used to make the test an accelerated test, and the maximum depth of the wear tracks was measured after the test. For the seizure resistance test, the load was gradually increased and the load at which the friction coefficient surged was treated as the seizure load.

Table 3. Conditions of reciprocating slide type friction tests.

Measurement item	Friction coefficient	Amount of wear	Load of seizure
Load , Time	Increase load to 510N in five minutes and maintain it for 60 seconds after running-in process (5N × 20sec)	Increase load to 300N in five minutes and maintain it for 1800 seconds after running-in process (5N × 20sec)	Increase load (1.4N/sec) after running-in process (5N × 20sec)
Stroke (mm)	1.0	←	←
Frequency (Hz)	10	50	←
Temperature (K)	403	300	←
Lubrication	Engine oil (10W40) 25ul dripping before Sliding test	Machine oil (Super marupasu 10) dipping	Engine oil (10W40) dipping
Shape of Opposite member	R8, Width 6mm	R40, Width 2mm	←

Bore Surface Sliding Test

On the small end of the connecting rod, since the bore surface slides on the piston pin, an evaluation in conditions that better simulate what occurs in an actual motorcycle is needed. Therefore, a bore sliding test simulating the small end was conducted. Figure 9 provides an overview of the testing equipment. A rotating body equivalent to a piston pin was designed to rotationally slide on the bore of a test piece (diameter of 17 mm and length of 16 mm) simulating the shape of the small end. The test was done under a variable sine-wave load condition that takes into account the inertial force present during actual use. On the small end, since the inertial force side (upper side) is thin and not very rigid, elastic deformation is large, and consequently peeling, wear of the coating film, or adhesion can easily occur. Therefore, the maximum inertial force of an actual motorcycle was used as the maximum load for the test. The surface treatments selected based on the results of the aforementioned reciprocating slide type friction test were applied to the bore surface of the test piece. Carburized, quenched and tempered SCM415 with surface hardness of 700 HV was used for the rotating body equivalent to a piston pin. Afterwards, a phosphate treatment was applied and then a molybdenum disulfide-based solid lubrication film was added. Table 4 shows the testing conditions. After the test, the external appearance of the coating film was inspected, and the amount of wear in the test piece simulating the small end and in the rotating body equivalent to a piston pin measured using a contact-type surface roughness tester.

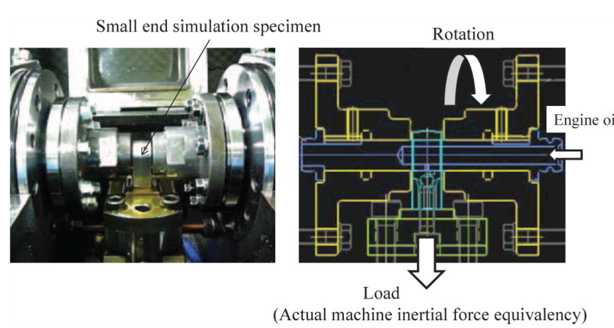

Figure 9. Summary of the inside diameter sliding test device.

Table 4. Condition of bore surface sliding test.

Load	Actual machine inertia load equivalency by sine wave (50Hz)
Time	3600sec.
Revolution speed of Pin	100rpm
Temperature	RT
Lubrication	Engine oil (10W40),10cm^{-3}/min

RESULTS AND DISCUSSION

Mechanical Characteristics

Fatigue strength and modulus of longitudinal elasticity, which are important functional characteristics of connecting rods, are discussed here. Figure 10 shows the results of fatigue strength tests performed on Ti-6Al-4V, Ti-5Al-1Fe and SCM420. The 10^7 cycle fatigue strength was nearly the same for Ti-6Al-4V and Ti-5Al-1Fe, and was 17-18% lower than that of SCM420. The modulus of longitudinal elasticity was approximately 210 GPa for SCM420, 111 GPa [10] for Ti-6Al-4V, and approximately 110 GPa [12] for Ti-5Al-1Fe. These results seem to indicate that titanium materials to be used for connecting rods cannot be designed in the same way as SCM420, but Ti-6Al-4V and Ti-5Al-1Fe can be considered essentially similar to each other.

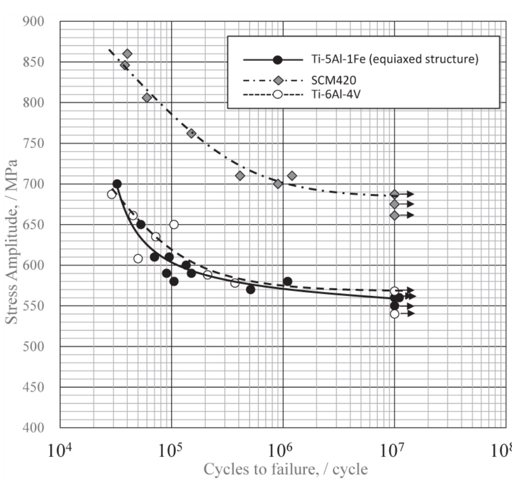

Figure 10. Fatigue strength.

FS Process Test

Figure 11 shows the Charpy impact values of Ti-5Al-1Fe at various temperature levels. The Charpy impact value at room temperature was 34 J/cm^2, approximately 13% smaller than the 39 J/cm^2 value for Ti-6Al-4V.

Figure 12 shows the effects of temperature and strain rate on the fracture surface characteristics based on an FS process test. The strain rate required for obtaining a brittle fracture surface at a temperature of 200 K or lower was at least 7.5 s^{-1} for SCM420, at least 38 s^{-1} for Ti-6Al-4V and at least 28 s^{-1} for Ti-5Al-1Fe.

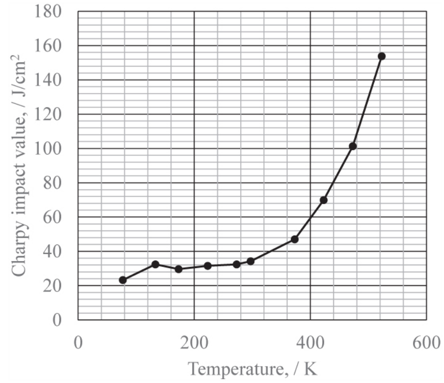

Figure 11. Results of Charpy impact tests.

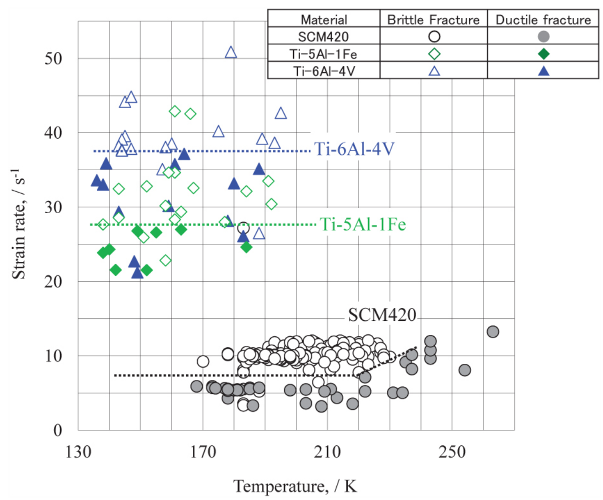

Figure 12. Relationship between temperature and strain rate.

The above results indicate that a higher strain rate than that required for an SCM420 connecting rod is needed when applying the FS process to a titanium connecting rod. These results also show that Ti-5Al-1Fe can be fractured using less energy and produce brittle fracture surfaces at a lower strain rate than Ti-6Al-4V.

Hot Workability Evaluation

Based on the ease of applying the FS process, the target titanium material was narrowed down to Ti-5Al-1Fe, which was then compared with SCM420. Figure 13 shows the tensile test results during hot working. In terms of the maximum tensile load, SCM420 had a lower value than Ti-5Al-1Fe at temperatures below 1,200 K, but this relationship reversed at temperatures of 1,200 K or higher. The value for Ti-5Al-1Fe at 1,223 K was nearly equal to the value for SCM420 at 1,323 K. The same trends were observed in the reduction rate of the cross-sectional area as well, and the value for Ti-5Al-1Fe at 1,223 K became nearly equal to the values for SCM420 at 1,323 K or higher. Figure 14 shows the compressive test results during hot working. The maximum compressive stress results showed the same trends as in the tensile test, and the value for Ti-5Al-1Fe at 1,223 K was nearly equal to the value for SCM420 at 1,373 K. As for the temperature increment quantity, the value for Ti-5Al-1Fe at 1,223 K was equal to the value for SCM420 at 1,273 K. The above results demonstrated that in the vicinity of 1,223 K, the stress associated with processing Ti-5Al-1Fe, i.e., the deformation resistance, and the drawability-which is expressed as the reduction rate of a cross-sectional area-are similar to the values for SCM420 at its hot-forging temperature (around 1,323 K). As for temperature increment quantity, the value for Ti-5Al-1Fe at 1,223 K is slightly higher than the value for SCM420 at its hot-forging temperature, but this is not expected to pose any problems during actual hot forging. If Ti-5Al-1Fe is hot-forged at 1,223 K or higher, there is a possibility that hot forging can be implemented using a die design similar to that used for SCM420.

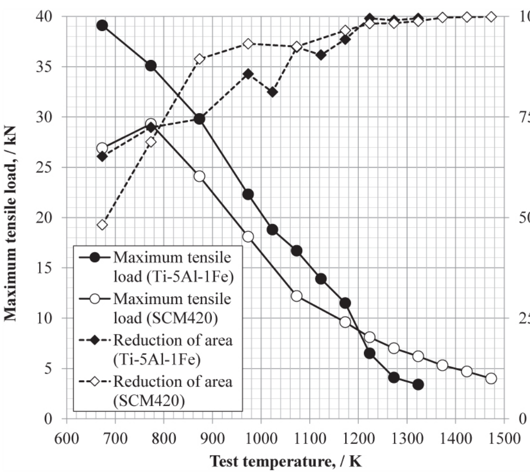

Figure 13. Test results of high speed tensile tests.

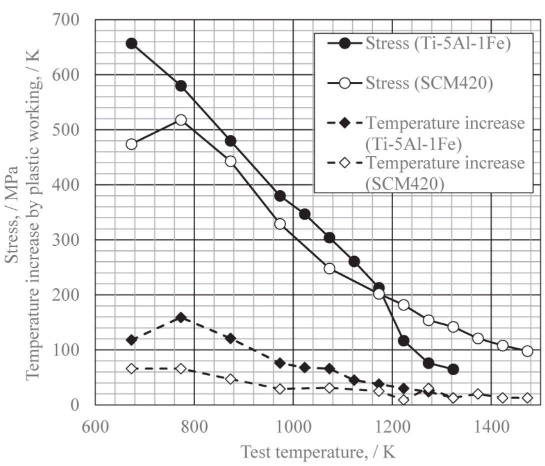

Figure 14. Test results of high speed compressive tests.

Meanwhile, the β transformation temperature of Ti-5Al-1Fe is 1,283 K [13]. That is, if Ti-5Al-1Fe is forged at 1,283 K or higher, an acicular structure is formed during forging, which will not return to an equiaxed structure even if subsequently annealed. Therefore, the fatigue strength of Ti-5Al-1Fe in its acicular structure was compared with an equiaxed structure forged at a temperature lower than the β transformation temperature (Figure 15). The 10^7 cycle fatigue strength in the acicular structure was 16% lower than that in the equiaxed structure, indicating that an equiaxed structure is required if the maximum level of connecting rod functionality is to be obtained. The above results indicate that the optimum hot-forging temperature for Ti-5Al-1Fe is at least 1,223 K but lower than 1,283 K.

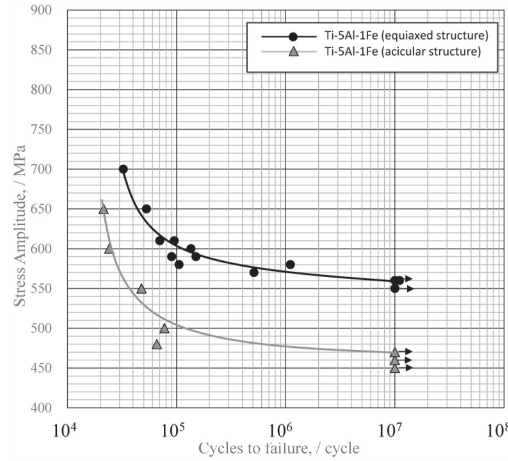

Figure 15. Fatigue strength.

Surface Treatment Selection

Reciprocating Slide Type Friction Test

Friction Coefficient

Figure 16 shows the results of friction coefficient evaluation. Ti-5Al-1Fe with no surface treatment had a friction coefficient that was over three times greater than that of SCM420. However, when surface treatments were applied, Ti-5Al-1Fe's friction coefficient was similar to that of SCM420, with the exception of TiAlN treatment. The friction coefficient of Ti-5Al-1Fe with TiAlN surface treatment was roughly twice that of Ti-5Al-1Fe with various other surface treatments. With all surface treatments except for TiAlN, the friction loss can be expected to be similar to that of SCM420.

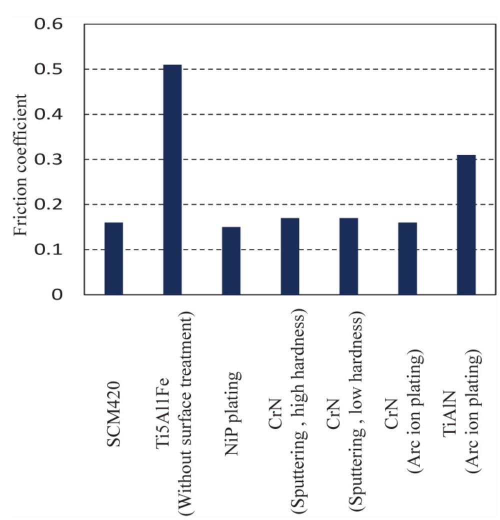

Figure 16. Friction coefficient in engine oil.

Wear Resistance

Figure 17 shows the relationship between the coating film hardness and the maximum wear track depth. Correlation was observed between the coating film hardness and the maximum wear track depth, regardless of the coating film type. NiP plating with low hardness and CrN (low hardness) may wear more easily than others.

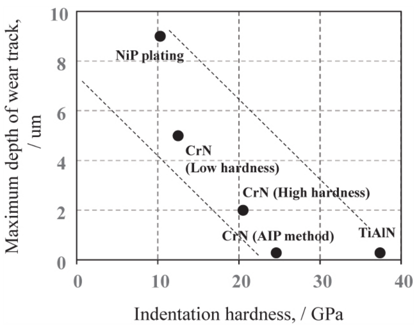

Figure 17. Indentation hardness and maximum depth of wear track.

Seizure Resistance

Figure 18 shows the results of the seizure load which follow the Weibull distribution [14]. NiP plating had the lowest seizure load, while TiAlN had the highest. Figure 19 shows an example of the external appearance of a test piece. With NiP plating, cracks and peeling was observed in the coating film near the adhered portion; therefore it can be surmised that the coating film became peeled during the test, exposing the base material, which then directly slid on the pin, leading to seizure. With other surface treatments, coating film peeling was not observed, and only slight scuff marks were seen. NiP plating can be considered to have a lower level of adhesion than other surface treatments.

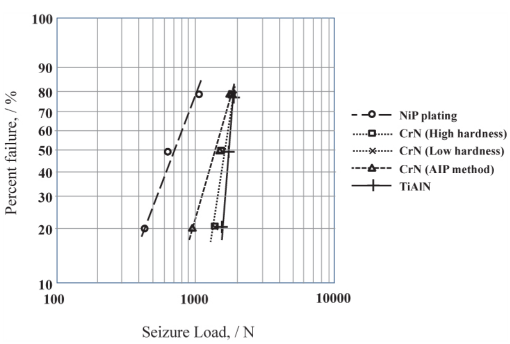

Figure 18. Seizure load.

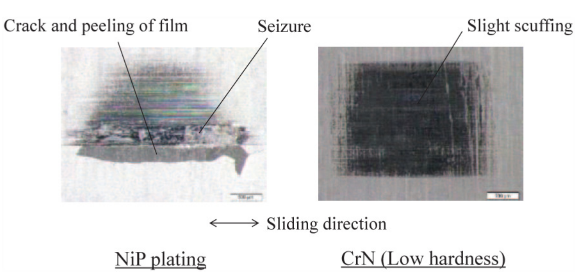

Figure 19. Appearance of test piece after sliding test.

Bore Surface Sliding Test

Based on the results of the aforementioned reciprocating slide type friction test, a bore surface sliding test was conducted for two specifications: CrN (high hardness) and CrN (Arc Ion Plating method). Figure 20 shows the external appearance of the small end test piece after the test, along with the shape measurement results using a surface roughness tester. CrN (high hardness) showed external peeling and height differences of approximately 4 µm (equal to the coating film thickness). Therefore, it can be surmised that the coating film became peeled at the boundary of the base material. No peeling was seen in CrN (Arc Ion Plating method). Even though they are both CrN surface treatments, the Arc Ion Plating method has a higher ionization rate than the sputtering method and is known to produce good throwing power property in the coating film, create a denser structure, and the higher reactivity with nitrogen gas results in a harder coating film [15]. It can be surmised that compared to CrN (high hardness), the CrN (Arc Ion Plating method) used in the test resulted in a more adhesive bore coating film for the same reason. In both cases, because a tool mark of roughly 3 µm remained on the base material, it can be deduced that abrasion did not continue. Furthermore, the amount of wear in the pin test piece, which was the opposing material, was 3 µm or smaller in both cases, which was smaller than the thickness of the solid lubrication film (5 µm).

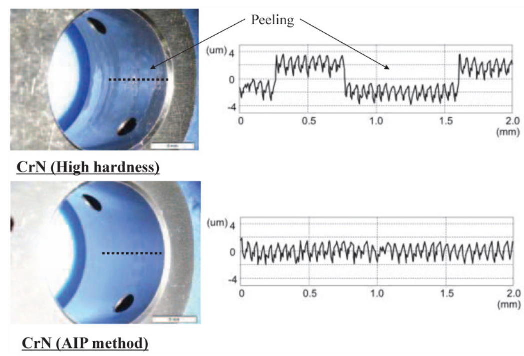

Figure 20. Appearances and surface roughness of test pieces after inside diameter sliding test.

Table 5 summarizes the results of the reciprocating slide type friction test and the bore surface sliding test. Based on the evaluation results of the friction coefficient, wear resistance, seizure resistance and adhesion on the bore, CrN (Arc Ion Plating method) is judged to be the best-suited surface treatment for titanium connecting rods.

Table 5. Test results.

A:excellent
B:good
C:poor

		Type of film	Friction coefficient	Wear resistance	Adhesion resistance	Film quality of inside diameter	
Plating		NiP Plating	B	C	C	-	
PVD	Sputtering	CrN (High hardness)	↑	B	B	C	
		CrN (Low hardness)	↑	C	↑	-	
	Arc ion plating (AIP)	CrN	↑	A	↑	A	⬅
		TiAlN	C	↑	↑	-	

CONCLUSIONS

With the aim of solving cost- and functionality-related issues and making titanium connecting rods usable in more motorcycle models, fatigue strength, FS process applicability, hot workability characteristics and surface treatment were examined.

The following insights were obtained:

1. The 10^7 cycle fatigue strength is nearly the same for Ti-6Al-4V and Ti-5Al-1Fe, and is 17-18% lower than that of SCM420. The

modulus of longitudinal elasticity of Ti-6Al-4V and Ti-5Al-1Fe is also similar and is lower than that of SCM420.

2. When applying the FS process to a titanium connecting rod, to obtain brittle fracture surfaces, a higher strain rate than that required for an SCM420 connecting rod is needed. Ti-5Al-1Fe can be fractured using less energy and produce brittle fracture surfaces at a lower strain rate than required for Ti-6Al-4V.
3. If Ti-5Al-1Fe is hot-forged at 1,223 K or higher, there is a possibility that hot forging can be implemented using a similar die design to that used for SCM420. If the β transformation temperature is exceeded during forging and an acicular structure is formed, the 10^7 cycle fatigue strength becomes 16% lower than that in the original equiaxed structure. Therefore, the optimum hot-forging temperature is at least 1,223 K but below 1,283 K.
4. Based on the evaluation results of the friction coefficient, wear resistance, seizure resistance and adhesion on the bore surface, CrN (Arc Ion Plating method) is the best-suited surface treatment for titanium connecting rods.

These results verified the possibility of producing titanium connecting rods possessing higher functionality and efficiency at lower costs than before. Titanium connecting rods produced with this method began in 2014 for use in mass-production motorcycles (Figure 2). A total of 33,000 such connecting rods have been produced as of the end of April 2015.

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ACKNOWLEDGMENTS

We would like to express our sincere apperception to Nippon Steel & Sumitomo Metal Corporation, ICS Corporation, and the many others who offered their valuable input and cooperation in our study and the application of its results in the production of connecting rods.