

Application of Vacuum Assisted Carbide Dispersion Carbonitriding to Connecting Rods

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ABSTRACT

In four-cycle single-cylinder motorcycle engines, high Hertzian stress is generated on and beneath the big-end surface of the connecting rod. If the surface strength would be improved, the diameter of the big-end could be made smaller, making the entire engine smaller and lighter. Therefore, application of carbide dispersion carbonitriding using a vacuum furnace (hereinafter referred to as "vacuum CD carbonitriding") on the big-end surface was investigated. Vacuum CD carbonitriding was carried out by three processes. The first was a CD carburizing process. This process is done to obtain granular cementite, but in order to avoid decreasing the strength, it is necessary to prevent the formation of coarsened cementite at the grain boundary. The second process was a refining process. This process is done for the purpose of refining the prior austenite grain size. The third process was a carbonitriding process. This process is done for the purpose of increasing hardness in the vicinity of the surface. The strength of vacuum CD carbonitrided specimen was evaluated using a ball-on-disk type rolling-contact-fatigue testing machine. Vacuum CD carbonitriding has six times as long lifetime as conventional carburizing has. Vacuum CD carbonitrided connecting rods have been used in single-cylinder motorcycle engines since 2011.

CITATION: Kubota, T., "Application of Vacuum Assisted Carbide Dispersion Carbonitriding to Connecting Rods," *SAE Int. J. Mater. Manf.* 7(1):2014, doi:10.4271/2013-32-9082.

INTRODUCTION

Single-cylinder motorcycle engines ([Figure 1](#)) use a needle roller bearing at the big-end of the connecting rod ([Figure 2](#)).



Figure 1. Motorcycle.

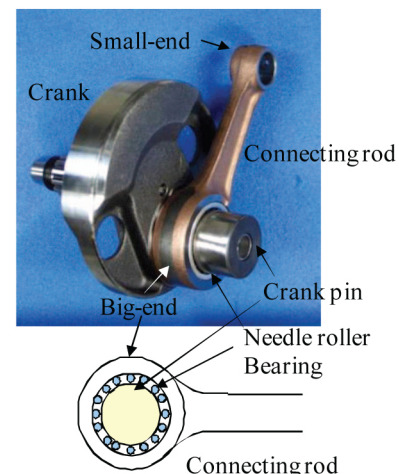


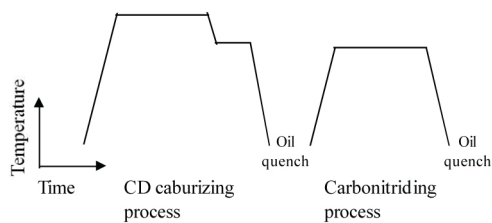
Figure 2. Crank shaft.

If the big-end can be reduced in diameter, a smaller, lighter engine can be achieved, but the contact stress (Hertzian stress) from the needle roller on the inner surface of

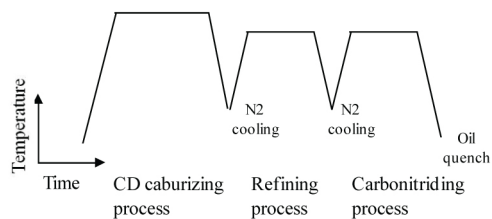
the reduced big-end would be greater, and the flaking failure lifetime (hereinafter called the “rolling contact fatigue lifetime”) would be reduced due to rolling contact fatigue. For that reason, increasing the strength of the inner surface of the big-end would extend the rolling contact fatigue lifetime, making it possible to reduce the size of the engine.

As a method of increasing rolling contact fatigue lifetime, Ooki et al.^[1] applied carbonitriding in place of carburizing, which had been done heretofore, for refining the prior austenite grain size. Furthermore, Yamagata et al.^[2] applied carbide dispersion carbonitriding (hereinafter called “CD carbonitriding”) using gas carburizing, and found that the rolling contact fatigue lifetime was 1.6 times that obtained by carburizing due to the effect of increased hardness in the vicinity of the surface because of granular cementite and carbonitriding. In this study, CD carbonitriding was done simultaneously with refinement of the grains through vacuum carburizing to try and achieve a rolling contact fatigue lifetime greater than that of previous gas CD carbonitriding.

Generally, in CD carbonitriding, a CD carburizing process is performed, followed by cooling of the specimen to the A1 transformation point, and carbonitriding in an ammonia atmosphere.^[2] On the other hand, it has been reported that if the carburizing process is followed by a process in which the temperature is kept cooler than that of the carburizing process (the refining process), grain refining is accomplished.^[1, 2, 3] Therefore, in this study, three processes—a CD carburizing process, a refining process, and a carbonitriding process—were undertaken (as shown in [Figure 3](#)), to see if CD carbonitriding with refined prior austenite grain size could be achieved. Compared to gas carburizing, it is easier to achieve rapid cooling of the specimen in vacuum carburizing through the nitrogen gas, so repetition of multiple processes can be performed with reduced costs.



(1). Gas CD carbonitriding. (Yamagata et al. [2])



(2). Vacuum CD carbonitriding. (This report.)

Figure 3. Processing conditions of CD carbonitridings.

The CD carburizing process, which is the first process shown in [Figure 3](#), accomplishes carburizing with a carbon

concentration above the eutectoid point, producing a stronger surface by dispersing the granular cementite within the austenite grains during cooling. It has been reported, however, that if coarsened cementite forms in the austenite grain boundary during the carburizing process, the rolling contact fatigue lifetime is decreased markedly.^[4,5] The conditions for the formation of coarsened cementite in the grain boundary, however, have yet to be elucidated. Therefore, in this study, CD carburizing processes were done while varying the process temperature and the ratio of carbon infiltration time to diffusion time, and the causes of coarsened cementite formation were examined.

In the subsequent refining process, temperature conditions that could produce a finer prior austenite grain size were studied. Compared to gas carburizing, vacuum carburizing enables carburizing at a higher temperature.^[3] On the other hand, high temperature processing generally produces a larger prior austenite grain size. Therefore, the respective temperatures of the CD carburizing process and the refining process were varied to find out what influence they had on the prior austenite grain size.

In the final carbonitriding process, for the purpose of obtaining a higher nitrogen concentration in order to increase the hardness in the vicinity of the surface, the effects of the process time and methods of ammonia injection on carbonitriding concentration were studied.

The degree to which the rolling contact fatigue lifetime could be raised in vacuum assisted CD carbonitriding with optimization of these three processes, as compared with conventional gas carburizing and CD carbonitriding, was investigated.

EXPERIMENTAL

SPECIMENS

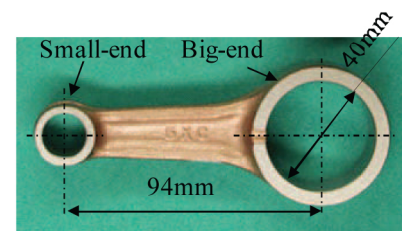


Figure 4. specimen.

Connecting rods for motorcycles were used as the specimens ([Figure 4](#)). The inner diameter of the big-end was 40 mm, and the distance between the center of the big-end and the center of the small-end was 94 mm. After hot forging, they were entirely copper-plated, and machined to produce an arithmetic mean roughness (Ra) of 6.3 to 12.5 μm for the inner bore and thrust surface of the big-end and small-end. The portions with copper plating had anti-carburization

protection, but the portions with machining could be carburized.

Additionally, in the rolling contact fatigue lifetime tests, disk-shaped specimens with 60 mm in outer diameter, 20 mm in inner diameter and 9 mm in thickness were used. The coarseness during carburization was from 6.3 to 12.5 μm arithmetic mean roughness. After carburization, 0.1 mm was ground off in the direction of thickness, giving an arithmetic mean roughness of 0.05 to 0.1 μm , and the resulting specimens were provided for testing.

JIS SCM420 steel was used as the material of the specimens in both cases. Table 1 shows its chemical composition.

Table 1. Chemical composition (wt%).

	C	Si	Mn	P	S	Ni	Cr	Mo
SCM420	0.21	0.22	0.86	0.015	0.006	0.09	1.11	0.15

EVALUATION METHODS

Evaluation of Characteristics

First, the inner bore of the big-end of the connecting rod was cut out in the radial direction, embedded in resin and buffed to polish it. Then, the prior austenite grain size and cementite grain size were measured using a metallographic microscope, and measurement of the carbon and nitrogen concentrations was also done. Regarding the prior austenite grain size, JIS G0551 was followed, with the recorded number of grains per unit area being used to calculate the average prior austenite grain size. Regarding the cementite grain size, the diameters of circumscribed circles around the cementite were measured. Regarding carbon concentration and nitrogen concentration, EPMA line analysis was conducted using a Shimadzu EPMA-1600 to determine the concentrations in percentage by mass.

Rolling Contact Fatigue Test

As a means of measuring rolling contact fatigue lifetime, thrust rolling contact fatigue tests were conducted.^[6] Figure 5 shows the testing method. Thrust force is applied via balls on the surface of a stationary specimen as the machine is turning. When flaking of the specimen occurs, the testing machine experiences abnormal vibration and stops. This was considered failure of the material, and the duration of the stress cycle to that point was considered the rolling contact fatigue lifetime. Table 2 shows the test conditions. In order to simulate contamination within an engine, 1 g of high-speed steel powder was added per liter of lubricant. Testing was conducted three or four times for each specification, repeating identical test conditions. The lifetimes obtained were assumed to follow a Weibull distribution, and the 10% failure probabilities and 50% failure probabilities (hereinafter, called “L10” and “L50,” respectively) were calculated.

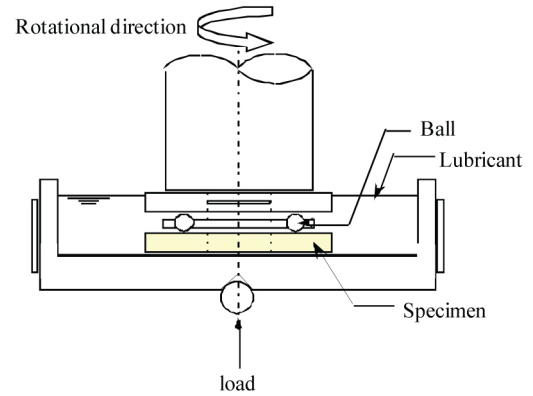


Figure 5. Schematic of thrust type rolling contact fatigue testing machine.

Table 2. Rolling-contact fatigue test conditions.

Maximum contact stress (Hertzian stress)	Pmax = 5300MPa
Loading speed	1500cpm (3 balls)
Ball	SUJ2 3/8 inch
Lubricant	Puresafety 10 (Cosmo)
Contaminant	Gas atomized powder of high speed steel Diameter: 105 - 150 μm Hardness: 750HV Quantity: 1g per Liter
Temperature	Room temperature

PROCESSING CONDITIONS

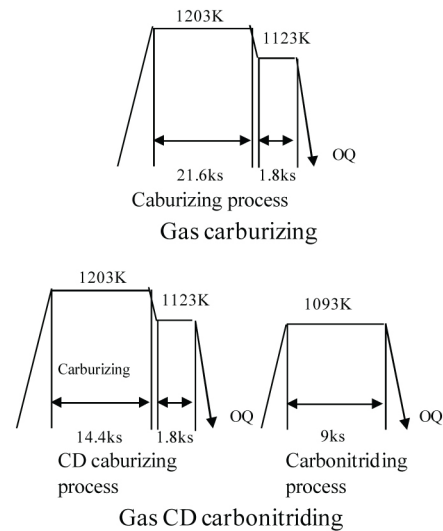


Figure 6. Processing conditions of gas carburizing and gas CD carbonitriding.

Processing consisted of three processes: CD carburizing, refining, and carbonitriding (Figure 3(2)). After the CD