Technical Trends of Large-size Drive Shafts for Rolling Mills

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Large-size drive shafts for rolling mills are required of more strength and longer service life within limited space. Koyo succeeded in developing universal joints that meet the demand thanks to its advanced manufacturing process and analysis engineering.

Together with product under development to be applied for the drive shafts in the future, the developed universal joints will contribute to improvement of reliability of the drive shafts.

Key Words*: drive shafts, rolling mill, high-strength, longer service life, universal joint*

1. Introduction

Cross type universal joints (hereinafter referred to as UJ), which can be used under high speed, large operating angle and heavy load conditions, are employed in a wide variety of applications, including automobiles, construction equipment, railway cars, ships, agricultural machinery, iron and steelmaking facilities and other industrial machinery, as joints for spindles. Joints for steel rolling mills are particularly required to have high load carrying capacity due to limited operating space. Koyo has been successful in developing universal joint spindles (hereinafter referred to as "drive shafts") for applications where higher load carrying capacity is required, and UJ with rotating diameters range from 350mm to 1 250mm have been widely applied. **Figure 1** summarizes Koyo's achievements and development maps corresponding to customers' ultimate target for improved drive shafts for work rolls of steel rolling mills. In recent years, there has been a tendency for rolls to be downsized for the purpose of improving rolling efficiency, which will accordingly lead to increased demands for downsizing and higher strength.

Introduced in this paper are some technology achievements by Koyo for improving strength and service life of higher load carrying capacity drive shafts.

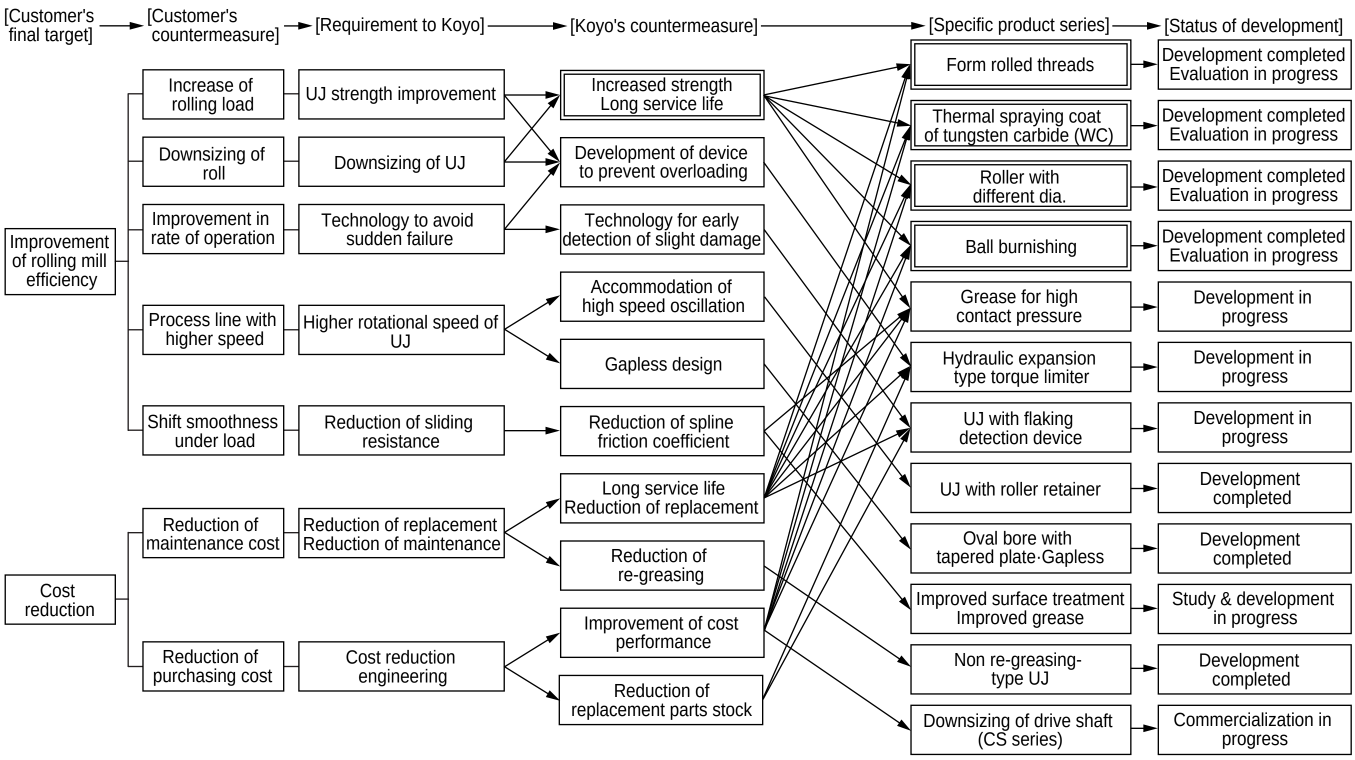

Fig. 1 Market trend of large-size drive shaft and development situation of Koyo

2. Structure of Large-size Drive Shafts

As for large-size drive shafts, block type universal joints are employed. **Figures 2** and **3** show the structure of drive shaft and UJ respectively.

This structure of UJ is comprised of four major components-a cross-shaped shaft (hereinafter referred to as cross), bearing cups, bolts and yokes. Although it has been designed to maintain the balance of strength among four components, bolts have been the weakest ones due to space limitation for mounting, and their strength is affected by external factors. Therefore, improvement in strength of the bolts and in bearing fatigue (flaking) life will enhance the whole strength and life of the joint.

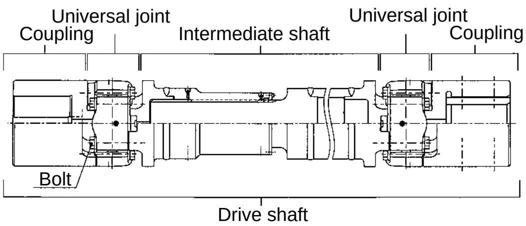

Fig. 2 Structure of drive shaft

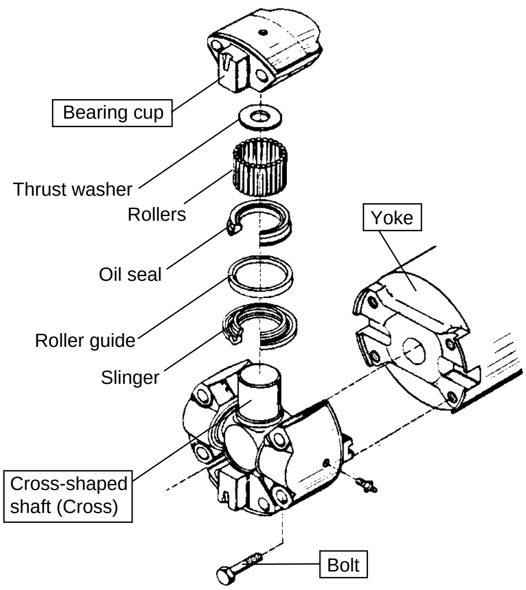

Fig. 3 Structure of universal joint

3. Improvement of Strength

3. 1 Improvement of Strength by Form Rolling after Heat Treatment of Bolt Thread

The thread on the bolt has conventionally been machined after heat treatment. However, by switching this process to form rolling after heat treatment, allowable fatigue stress at the bottom radii of the thread increases significantly. (Conventional form rolling machines could not form the large-diameter bolts after heat treatment. Now, improved form rolling machines have made it possible.)

Specifically, the form rolled thread differs from the machined thread in the following aspects:

① Fiber flow is formed along the shape of the thread (**Fig. 4**).

② Residual compressive stress at subsurface beneath the bottom radius of the thread increases (**Fig. 5**)

Hereinafter, "form rolling" and "form rolled" are expressed as "rolling" and "rolled," respectively.

In order to confirm improvement of performance by rolling in comparison with machining, a fatigue strength test was conducted. Outline of the test and its results are described hereafter.

Fig. 4 Fiber flow of rolled thread

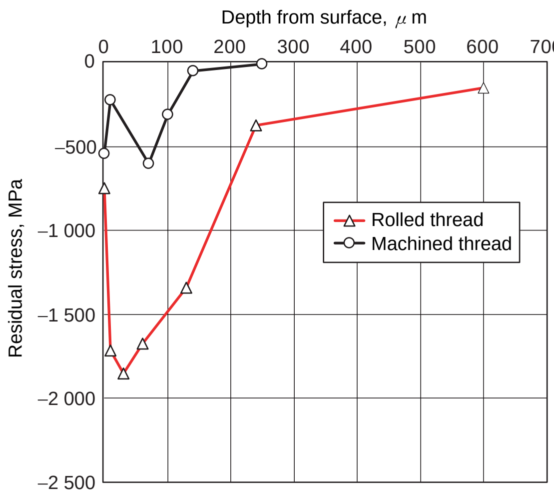

Fig. 5 Residual compressive stress distribution of rolled thread

3. 1. 1 Outline of Test

Specifications of the tested bolts are shown in **Table 1**. **Figure 6** shows schematic of the test machine.

Table 1 Bolt specifications for the test

Bolt No.	A	B	C
Type	Machined bolt	Bolt rolled after heat treatment	Bolt heat treated after rolling
Quantity	40	40	40
Size	M14, P1.5		
Strength class	12.9 (SCM435)		
Bolt body dia.	ϕ 11.5		
Length under head, mm	137		

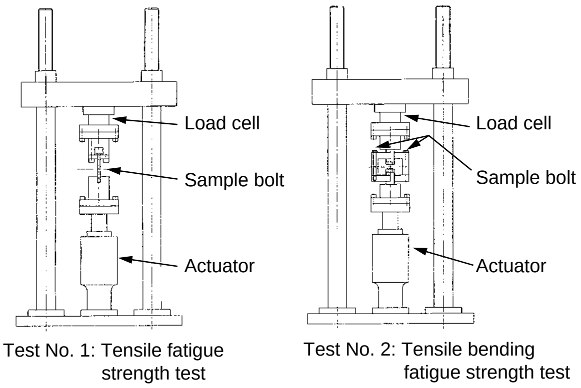

Fig. 6 Schematic diagram of test machine

3. 1. 2 Test Result

Test results are summarized in SN charts as shown in **Fig. 7**.

In this test, a bolt specimen was subjected to both tensile and bending stresses in a number of different ratio conditions in order to obtain the fatigue limits. As a result, 30% (1/3.3) of the bending stress was equivalent to the tensile stress. When evaluated under this equivalent stress condition, the machined bolt had allowable stress amplitude of 60 MPa, whereas the bolt rolled after heat treatment had 112 MPa, and the bolt heat treated after rolling had 72 MPa. From these findings, it was confirmed that the fatigue limit was improved 1.9 times (= 112/60) by rolling after heat treatment (the effect of fiber flow plus residual compressive stress). On the other hand, the effect of fiber flow only was found to be 1.2 times (= 72/60).

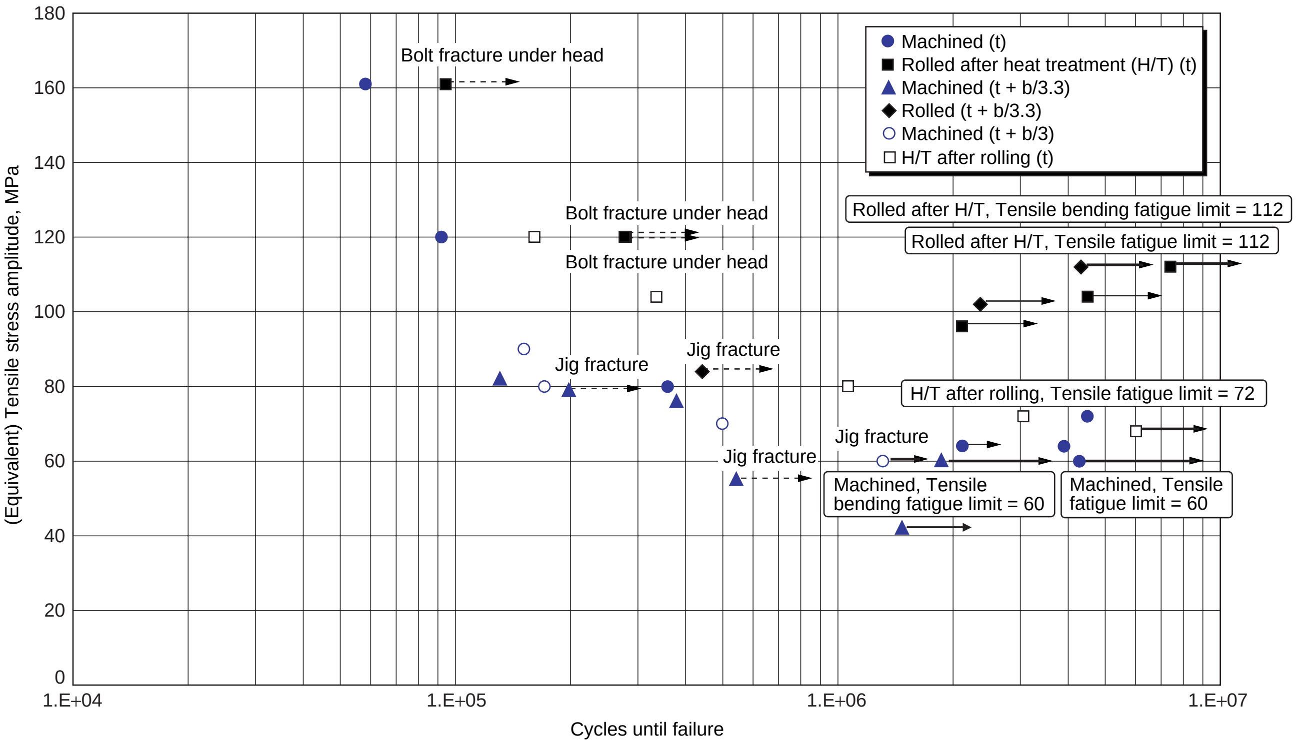

Fig. 7 Result of tensile and bending tests on bolt

3. 2 Improvement of Strength by Thermal Spraying Coat of Tungsten Carbide (WC) on Bearing Cup Key

In drive shafts for hot rolling mill applications, standard specification of rust prevention on the key area is to apply carburizing steel for the bearing cup and stainless steel (hereinafter referred to as "SUS") welding on the key way surface of the yoke (**Fig. 8**). Depending on the ambient atmosphere, however, long-term service may result in corrosion on the side face of the bearing cup key (carburized area), which may lead to clearance between the key and the key way. This clearance results in increasing the bending stress on the bolts and hence affecting the strength thereof.

One possible method to decrease this phenomenon is to apply thermal spraying coat of tungsten carbide (hereinafter referred to as "WC") which is more corrosion resistant than carburizing steel, and which generates less electric potential difference (less electrochemical corrosion) with the welding SUS layer on the mating key way.

Since the thermal spraying coat is applied on the loaded areas on key surface, an evaluation test as described below was conducted to make sure that loading would not cause any problems.

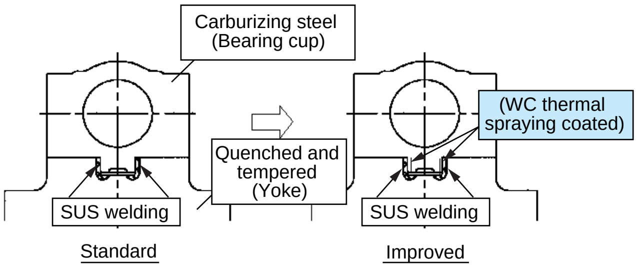

Fig. 8 Rust prevention specification around key section

3. 2. 1 Salt Spray Test

Test conditions are shown in **Table 2**.

After salt spray for 200 hours, no rust was found, which showed rust preventive effect of the treatment.

Table 2 Test conditions

Humidity in cabinet, %	98
Temperature in cabinet, ℃	35
Concentration of salt water, %	5
Inclination of sample surface, °	45° against horizontal surface
Time, h	200 (observed at 0 and after 1, 20, 50, 100 hours)
Salt spray tester model	ISO-3-CY, R Type

3. 2. 2 Static Contact Stress Loading Test

The test piece after the salt spray test was subjected to a static contact stress of 50～392 MPa to examine if the WC coated surface would have any cracks under static load. **Figure 9** shows a sketch of Amsler tester.

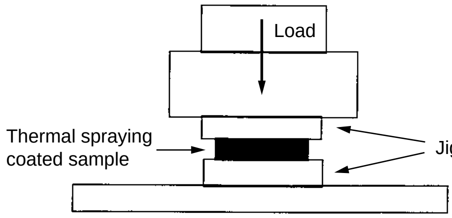

Fig. 9 Amsler tester

The test result showed no crack up to the loading of 392 MPa.

Figure 10 shows a cross section of microstructure of WC coated surface after the test.

Figures 11 and **12** show rust preventive effect on actual machines. This shows that WC coating is effective for preventing the decrease of bolt strength.

It is also expected that restraining the generation of clearance due to corrosion at the key area will improve the fatigue life of the bearing through minimizing non-uniform load distribution and heavier load on raceways at the end of the cross besides the bolt strength improvement.

Fig. 10 Cross section of microstructure of WC coated surface after test

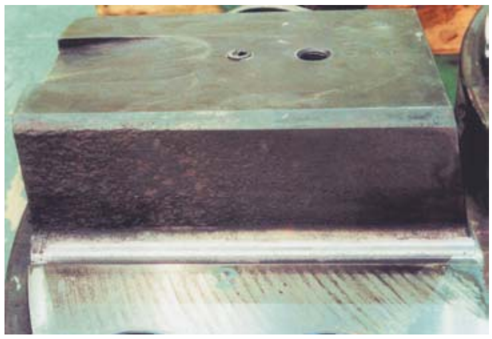

Fig. 11 Without WC coat
(1.52mm wide corrosion wear generated after 13 month use)

Fig. 12 WC coated product
(no dimensional change in key width after 20 month use)

4. Improvement of Bearing Flaking Life

4. 1 Application of Different Diameter Rollers Based on FEM Analysis

Because the cross is an elastic cantilever beam and the bearing has some radial clearance, the load on the cross generally becomes heavier toward the end of the cross. This phenomenon is consistent with actual mode of flaking.

In order to improve this phenomenon, load on the roller is made uniform by designing the roller to have a minutely smaller diameter at the very close end, which would improve flaking life of the bearing. The finite element method (FEM) analysis has been used to find the optimum roller design. Until recently, however, simplified three-dimensional (3D) FEM analysis, as shown in **Fig. 13**, assuming only cross and rollers to be elastic bodies, was used. Today, with advanced FEM analysis technology, a new 3D FEM analysis model integrating all of five components including the bearing cup, yoke and bolts as ones combined elastic body, is used for closer simulation of an actual drive shaft.

A new 5-component integrated 3D analysis shown in **Fig. 14**, was carried out. It was found that the roller diameter difference based on the conventional analysis was not enough to uniform the load. This result concluded that the influence of elastic deflection of a bearing cup was so large. Therefore, uniform load to the roller was achieved by providing further roller diameter difference. As an actual machine showed stronger contact trace at the end of the cross, a new design roller, based on the new 3D FEM analysis, is being evaluated now for its effects.

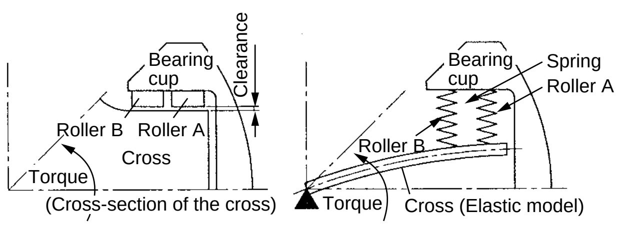

Fig. 13 Conventional conditions of analysis model

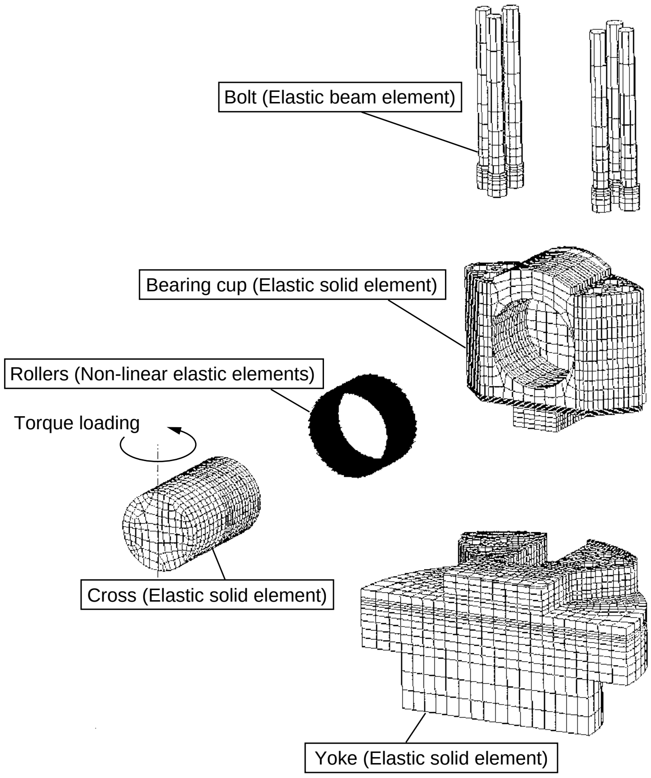

Fig. 14 Improved FEM analysis model (mesh distributions)

4. 2 Ball Burnishing on Cross Shaft

It is considered that there are the following two approaches to improve the flaking life of cross raceway from the standpoint of material properties.

· Increasing the hardness of the raceway surface
· Increasing the residual compressive stress in the subsurface of the raceway

To realize these, shot peening was conventionally used. Koyo has developed and is now evaluating ball burnishing on the cross raceway because of the following four advantages. The process is shown in **Fig. 15**.

① Because ball burnishing applies rolling contact of super-hard ceramic balls backed up hydraulically on the metallic raceway surface, this is a reliable plastic working process that can produce durable surface finish.

② As plastic working increases the surface hardness and the subsurface residual compressive stress, flaking life is improved. (Basically similar principle to a shot peening, but the effect of ball burnishing goes deeper than that by the shot peening.)

③ Raceway roughness is improved since protrusions on the raceway surface are removed. And no further finishing process is required. (Shot peening requires additional finishing process.)

④ As the ball burnishing fixture can be used by attaching to lathe or other machine, there is actually no limitation in size of workpieces. (Shot peening has limitation of workpieces up to 600 kg.)

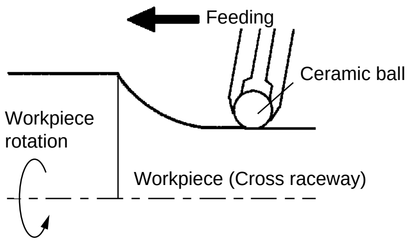

Fig. 15 Ball burnishing process method

Evaluation results with test pieces are shown below.

1) Residual Compressive Stress

Figure 16 shows measurement results of residual compressive stress on ball burnished and shot peened test pieces. The ball burnished piece showed ranges of increase more than twice as deep as the shot peened piece. As a typical starting point of flaking was approximately 0.15~0.30mm deep subsurface in case of hot rolling mill application, the deeper is the range of increase of residual stress, the more effective the depth is against flaking.

· Residual compressive stress with shot peening→
Max. approx. 1 320 MPa (at 0.06mm deep) ×
range of increase approx. 0.20mm

· Residual compressive stress with ball burnishing→
Max. approx.1 080 MPa (at 0.12mm deep) ×
range of increase approx. 0.45mm

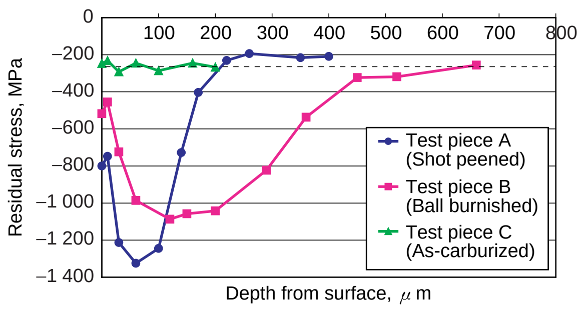

Fig. 16 Measurement result of residual compressive stress

2) Hardness Distribution

Figure 17 shows hardness distribution measured.

Hardening range by ball burnishing was twice as deep as that by shot peening.

· Range of hardening by shot peening→ Approx. 0.2mm

· Range of hardening by ball burnishing→ Approx. 0.4mm

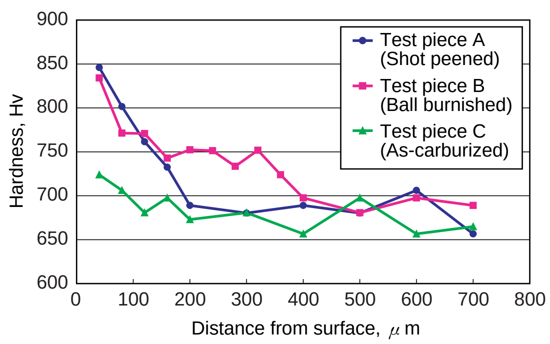

Fig. 17 Measurement result of hardness

The above test results show that ball burnishing is more effective against subsurface flaking than shot peening due to deeper range of residual compressive stress, and will be also beneficial against surface initiated flaking due to increased surface hardness.

5. Conclusions

Improvement of life and strength of universal joints for heavy duty drive shafts is effective for extending maintenance intervals which is demanded by customers. Koyo will continue the development of such heavy duty drive shafts as shown below:

① Products contributing to avoiding sudden failures

② Products contributing to saving in maintenance cost

Besides universal joints, Koyo would like to develop drive shafts including intermediate shafts and couplings so as to respond to recent market needs.

Reference

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