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Tribology International 39 (2006) 856–862
TRIBOLOGY INTERNATIONAL
www.elsevier.com/locate/triboint

Rolling contact fatigue of alumina ceramics sprayed on steel roller under pure rolling contact condition

Masahiro Fujii[a,*], Akira Yoshida[a], Jiabin Ma[b], Sadato Shigemura[c], Kazumi Tani[c]

[a]*Department of Mechanical Engineering, Okayama University, Tsushima-Naka, Okayama 700-8530, Japan*
[b]*The Graduate School of Natural Science and Technology, Okayama University, Tsushima-Naka, Okayama 700-8530, Japan*
[c]*Tocalo Co., Ltd., Fukae-Kitamachi, Higashinada-ku, Kobe 658-0013, Japan*

Received 14 October 2004; received in revised form 20 June 2005; accepted 12 July 2005
Available online 10 October 2005

Abstract

The rolling contact fatigue of sprayed alumina ceramics with a nominal composition of Al_2O_3–2.3 mass% TiO_2 was studied with a two-roller test machine under a pure rolling contact condition with oil lubricant. The influence of undercoating of sprayed Ni-based alloy on the rolling contact fatigue was investigated. The failure mode of all sprayed rollers was spalling caused by subsurface cracking. The undercoating did not contribute to the improvement of the rolling contact fatigue life. The elastic modulus of the alumina sprayed layer evaluated with the nano-indentation method was around 85 GPa. The depths of the observed subsurface cracks corresponded approximately to the depths where the orthogonal shear stress or the maximum shear stress calculated with two-dimensional FEM became maximum.

Keywords: Rolling contact fatigue; Spraying; Alumina ceramics; Oil lubrication; Nano-indentation; Stress analysis

1. Introduction

Thermal spraying is one kind of surface modification treatment utilized in almost all industrial fields. The thickness of a sprayed layer ranges from several μm to dozens of mm. Various kinds of materials such as metals, ceramics and plastics can be used as spraying material. The alumina ceramics employed in this study have high hardness, superior chemical stability and high resistivity; thus, the alumina ceramics are frequently used when corrosion resistance, wear resistance and electric insulation are required. However, the fracture toughness of the alumina ceramics is low. Hence, there are hardly any applications to machine elements under concentrated load conditions such as point and line contacts. On the other hand, when sprayed on the surface of materials such as steel, which has a high fracture toughness value, the alumina ceramics are expected to be applicable under comparatively heavy loads as well as to improve the wear and corrosion resistance of the surface. In order to apply alumina ceramics spraying to various rolls and some other rolling contact machine elements, it would be very useful to acquire the knowledge about its rolling contact fatigue and surface damage. Although the rolling contact fatigue of WC cermet and WC-Co sprayed layer has been studied [1–3], reports on mechanical properties and rolling contact fatigue of the sprayed layer of alumina ceramics are few.

In this study, the rolling contact fatigue of alumina ceramics sprayed on steel rollers was investigated under a pure rolling contact condition with oil lubricant. Moreover, the modulus of elasticity of the sprayed layers was evaluated using a thin film hardness tester based on the nano-indentation method. The failure mode was also discussed in terms of subsurface stresses.

2. Test rollers and spraying condition

Fig. 1 shows the shapes and dimensions of the test roller and the mating roller. The rollers were made of bearing steel SUJ2 (JIS) and 0.45% carbon steel S45C (JIS). The test rollers with a contact width of 8 mm were sprayed with

*Corresponding author. Tel.: +81 86 251 8035; fax: +81 86 251 8266.
E-mail address: fujii@mech.okayama-u.ac.jp (M. Fujii).

0301-679X/$ - see front matter
doi:10.1016/j.triboint.2005.07.038

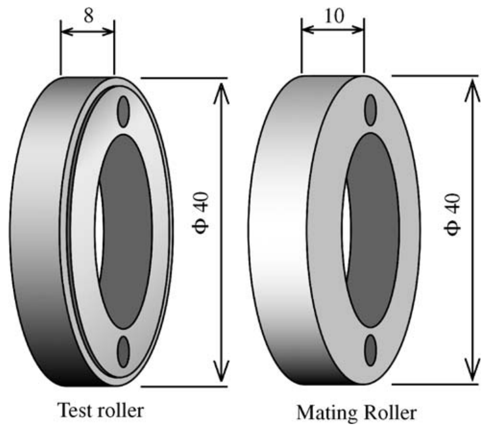

Fig. 1. Shapes and dimensions of roller specimens.

Table 1
Spraying condition

Alumina ceramics (plasma spraying)	
Arc current (A)	600
Arc voltage (V)	65
Plasma gas flow rate (l/min)	
Primary (Ar)	41
Secondary (H_2)	10
Spraying distance (mm)	120
Ni-based alloy undercoating (HVOF)	
Oxygen (l/min)	16
Kerosene (l/min)	0.75
Combustion pressure (MPa)	0.61
Spraying distance (mm)	380

alumina ceramics. The mating rollers without the sprayed layer have a width of 10 mm. The SUJ2 rollers were quenched in oil after being heated to 1123 K and were tempered at 433 K. The S45C rollers were quenched in water after being heated to 1123 K and were tempered at 873 K. For the SUJ2 rollers, alumina ceramics were sprayed on their surface directly (hereinafter called BSR1) or after a nickel-based alloy undercoating (hereinafter called BSR2). For the S45C rollers, alumina ceramics were sprayed after a nickel-based alloy undercoating (hereinafter called CSR2).

The spraying condition of alumina ceramics and undercoating condition of nickel-based alloy are shown in Table 1. The three kinds of sprayed rollers used in this study are listed in Table 2. Alumina ceramics with a nominal composition of Al_2O_3–2.3 mass% TiO_2 were deposited with an atmospheric plasma spraying process. The thickness of the layer laminated by each spraying process was about 20 μm. The nickel-based alloy was deposited with a high-velocity oxygen fuel (HVOF) process for the purpose of fine microstructure of the sprayed layer. The diameters of the sprayed particles of both the alumina ceramics and the nickel-based alloy were 10–45 μm. All the sprayed rollers were finished by grinding. For the sprayed rollers without an undercoating, the thickness of the sprayed layer of alumina ceramics was 1.2 mm. For the sprayed rollers

Table 2
Test roller

Specimen		BSR1	BSR2	CSR2
Roller material		SUJ2	SUJ2	S45C
Thickness	Al_2O_3 spraying (mm)	1.2	1.0	1.0
	Ni-based alloy undercoating (mm)	—	0.2	0.2

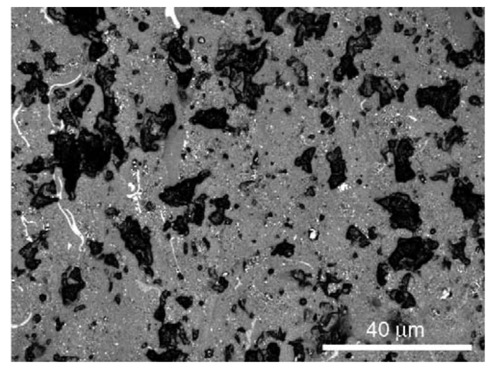

Fig. 2. Observation of sprayed layer.

with a nickel-based alloy undercoating, the thicknesses of alumina ceramics and nickel-based alloy layers were1.0 and 0.2 mm, respectively. With a view to reducing the influence of the difference of thermal expansion between the matrix and the sprayed layer, the practically sufficient thickness of the nickel-based alloy undercoating was 0.05–0.075 mm, where the microstructure of particle laminations was almost continuous. In this study, however, the thickness of the sprayed nickel-based alloy layer was 0.2 mm, with additional consideration of environmental insulation. The surface of the sprayed roller was sealed with epoxy resin to prevent the infiltration of lubricant into surface pores.

The arithmetic surface roughnesses of the sprayed roller and the mating roller were about 0.37 and 0.31–0.43 μm Ra, respectively. The average hardnesses of the sprayed layer and the matrix (SUJ2 steel), which were measured with a thin film hardness tester that was used for evaluation of elastic modulus mentioned later, were *HUT* 406 and *HUT* 225 kg f/mm^2, respectively.

Fig. 2 shows the surface observation of sprayed layer. The average porosity was around 26%.

3. Test method

The rolling fatigue test was performed under a pure rolling contact condition with a spring loading type two-roller test machine shown in Fig. 3. Each roller was driven with an individual electric motor, and the rotation speed of both rollers was 2000 rpm. The average rolling velocity of the rollers was 4.2 m/s. The lubricating oil was #83 turbine oil. The testing load per unit width W/L (W—load, L—contact width) was 100–200 N/mm. An acceleration pickup