# Effects of Contact Width and Pressure on Traction Characteristics in Traction Drive of Concave and Convex Roller Pair

**Kouitsu MIYACHIKA*[1] and Yuhichi ONO*[2]**

*1 Department of Mechanical and Aerospace Engineering, Tottori University
4-101 Minami, Koyama-cho, Tottori 680-8552, JAPAN
miya@mech.tottori-u.ac.jp

*2 Department Mechanical and Aerospace Engineering, Tottori University
4-101 Minami, Koyama-cho, Tottori 680-8552, JAPAN
ono@mech.tottori-u.ac.jp

## Abstract

The transmitted torque, the roller surface temperature, the specific sliding and the average electric voltage (oil film formation) between concave and convex rollers were simultaneously measured for the cases using traction oils TD22 and SANTOLUBES32 under different running conditions by means of a concave and convex roller test machine, which had been developed by the authors, and then the traction curves and the oil film formations were obtained. On the basis of these results, effects of specific sliding, contact pressure and roller speed on the traction coefficient, the roller surface temperature and the oil film formation were determined.

**Keywords:** traction drive, concave and convex roller pair, traction coefficient, oil film formation, roller surface temperature, specific sliding

## 1 Introduction

Recently CVT (Continuously Variable Transmission) using traction drives such as the epicyclic roller transmission is become great concern into use. There are a lot of convex-convex roller pairs and concave-convex roller pairs in these drives. Many studies on traction drives have been reported [1]-[3]. Most of these studies have treated the traction characteristics of a convex-convex roller pair. Some traction drives such as the epicyclic roller transmission consist of a concave and convex roller, so it has become necessary to determine the traction characteristics of a concave-convex roller pair for the design. The effects of the specific sliding, the contact pressure, the roller speed and the surface roughness on traction characteristics of concave-convex roller pair and the limit transmissible torque in traction drive of concave-convex roller pair were determined experimentally by Oda and Miyachika *et al*. [4] and also theoretically by Nonishi *et al*. [5]. The traction character- istics and the power transmission efficiency in traction drive of concave and convex roller in cases using traction oils TD10, TD22 and KTF-1 had been published by the authors [6]-[7]. Effect of traction oil on power loss of spur gear drive had been reported by Ikejo *et al*. [8].

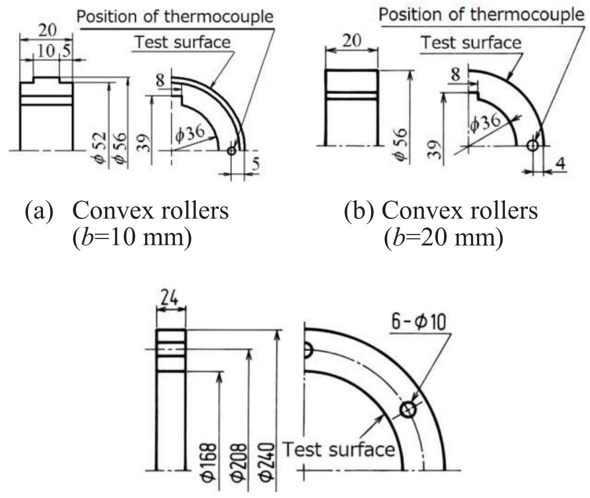
In the present paper, traction characteristics in traction drive of concave and convex roller pair in cases using traction oils TD22 and SANTOLUBES32. The transmitted torque, the roller surface temperature, the specific sliding and the average electric voltage between concave and convex rollers were simultaneously measured for the cases using traction oils TD22 and SANTOLUBES32 under different running conditions by means of a concave and convex roller test machine, which had been developed by the authors, and then the traction curves and the oil film formations were obtained. On the basis of these results, effects of specific sliding, contact pressure and roller speed on the traction coefficient, the roller surface temperature and the oil film formation were determined.

## 2 Experimental Method and Apparatus

### 2.1 Test rollers

The shapes and dimensions of test rollers are shown in **Fig. 1**. The outer diameter of the convex roller is 56 mm and the inside diameter of the concave roller 168 mm. The width of contact parts between these rollers is 10 and 20 mm. The materials, working and heat treatment conditions and surface roughness of the test rollers used are shown in **Table 1**.

**Table 2** shows the chemical properties of traction oils used in this experiment. TD22 and SANTO-LUBES32 are manufactured by NIPPON OIL CORPORATION and SantoLubes LLC, respectively.




(a) Convex rollers ($b$=10 mm)
(b) Convex rollers ($b$=20 mm)
(c) Concave rollers

**Fig. 1 Shapes and dimensions of test rollers**

### 2.2 Concave and convex roller test machine

**Figure 2** shows the concave and convex roller test machine used in this experiment. The concave roller is supported by bearing fixed to a movable pedestal. The convex roller is inscribed inside the concave roller. Test rollers are loaded by pressing the pedestal with a hydraulic cylinder. The convex roller is coupled to a V-S motor which has a capacity of 7.5 kW, and the concave roller to a direct current (DC) electrical machine (maximum torque 23.5 Nm). The DC electrical machine is able to drive or brake the concave roller, according to its use as a power or as a power absorber. By varying the field current of the DC electrical machine, it is possible to control the rotational speed of the concave roller and also the amount of sliding between concave and convex rollers. In this way, continuous adjustment of the specific sliding and the transmitted torque are possible, and the pure rolling can be achieved. The state of the oil film formation between concave and convex rollers suitably insulated can be measured using an electric resistance method.

### 2.3 Experimental method

The simultaneous measurements of specific sliding, transmitted torque and roller surface temperature, which are an important factor in the performance of lubricating oil, in the contact between a concave and convex roller pair under different running conditions were carried out by using the concave and convex roller test machine and measuring system shown in **Fig. 3**. The output signals from rotary encoder I, II (number of output pulses: 1200/rev.), from torque meter I (**Fig. 2**) and from a thermocouple embedded on the convex roller side (**Fig. 1**) were simultaneously memorized in the data logger, and then these signals were processed by a microcomputer and the results were recorded on the hard disc. The specific sliding is defined as $s = (u_1 - u_2) \times 100 / u_1$ [%], where $u_1$ and $u_2$ are the circumferential velocities of convex and concave rollers, respectively.

The state of the oil film formation between concave and convex rollers was measured using an electric resistance method [9]. The electric circuit used is shown in **Fig. 4**. A voltage of 15mV was imposed between a-b while the test rollers were isolated, and the variation of the voltage $E_{ab}$ were recorded on the data logger. The traction oil filtered was supplied to the inlet side of the contact through a nozzle at the rate of 1 L/min. The inlet oil temperature was kept constant at 313K [40ºC] by means of the thermostat.

**Table 1 Test rollers**

| Roller pairs | Roller pairs ($b$= 10 mm) | | Roller pairs ($b$= 20 mm) | |
|---|---|---|---|---|
| Roller | Convex roller | Concave roller | Convex roller | Concave roller |
| Materials | SCM415 | | SCM415 | |
| Treatment conditions | Case-hardened, Fine ground | | Case-hardened, Fine ground | |
| Vickers hardness HV | 703 | | 703 | |
| Surface roughness $R_z$ μm | 0.200 | 0.455 | 0.250 | 0.438 |
| $\Sigma R_z$ μm | 0.655 | | 0.688 | |

**Table 2 Chemical properties of traction oils**

| Traction oil | | TD22 | SANTOLUBES32 |
|---|---|---|---|
| Density at 15 ℃ g/cm$^3$ | | 0.861 | 0. 890 |
| Kinematic viscosity mm$^2$/s | 40 ˚C | 21.6 | 30.0 |
| | 100 ˚C | 3.60 | 5.12 |
| Viscosity pressure coefficient $\alpha$ GPa$^{-1}$ | | 38.20 | 36.37 |
| Viscosity index | | 1 5 | 75 |
| Flash point | ˚C | 130 | 154 |
| Pour point | ˚C | <-50.0 | <-42.0 |

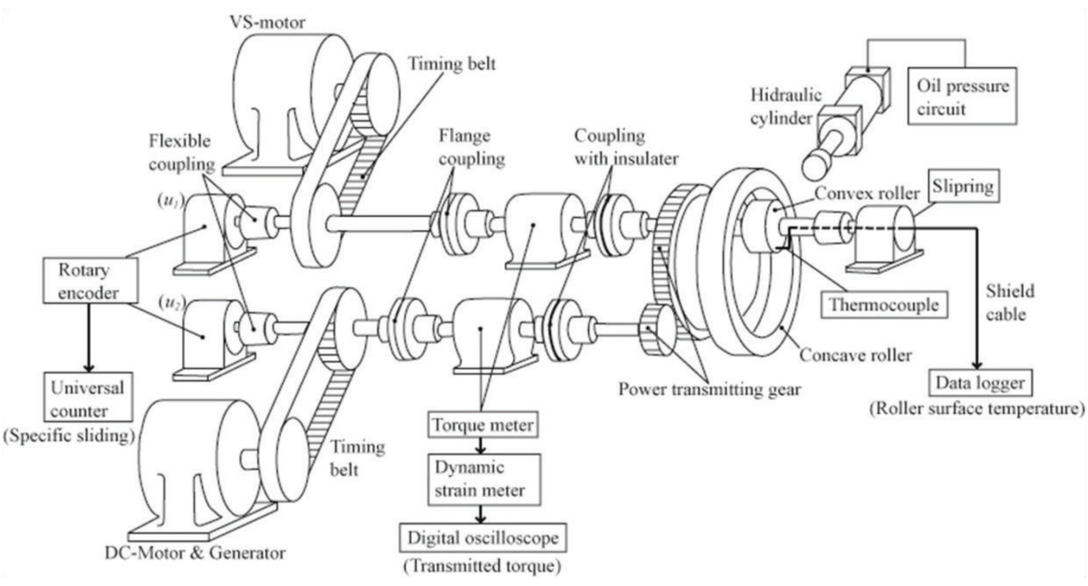



**Fig. 2 Concave and convex roller test machine**

## 3 Experimental Results and Discussions

### 3.1 Oil film formations

**Figure 5** shows the relation between oil film formation *F* and specific sliding *s* for TD22 under the running condition of convex roller speed $n_1$=1000, 2000rpm and various contact pressure $p_{max}$ (Hertzian maximum contact pressure). In **Fig. 5**, *b* denotes the contact width. It is seen from **Fig. 5** that F deteriorates with increasing $p_{max}$ and s and decreasing $n_1$ and *b*.

**Figure 6** shows the relation between *F* and *s* for SANTOLUBES32 under the running condition of $n_1$= 1000 rpm and various $p_{max}$. **Figure 7** shows the relation between *F* and *s* for TD22 and SANTO LUBES 32 under the running condition of various n1 and $p_{max}$=450, 693MPa. *F* of SANTOLUBES32 is far superior to *F* of TD22.

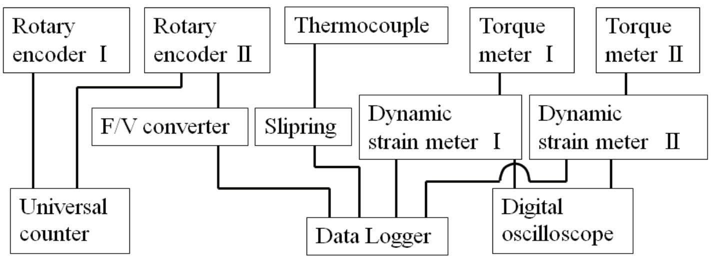



**Fig. 3 Block diagram for simultaneous measurements**

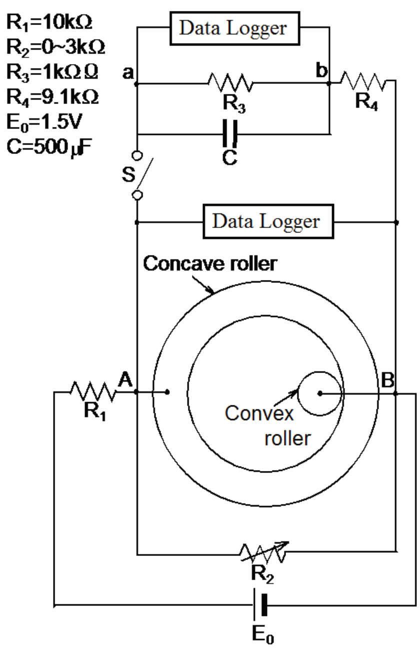
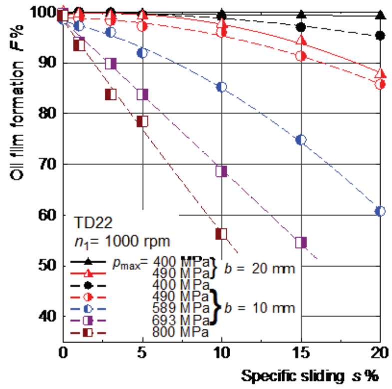
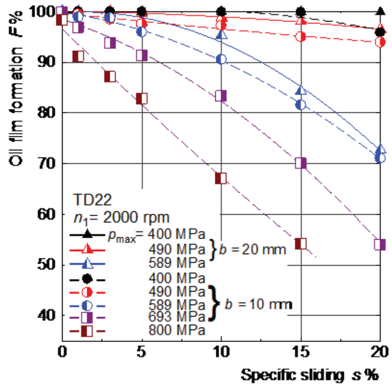



**Fig. 4 Electric circuit for measuring oil film formation**

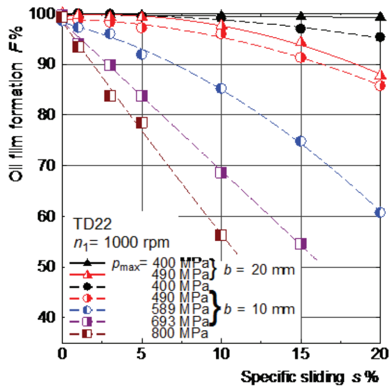



(a) $n_1$=1000 rpm

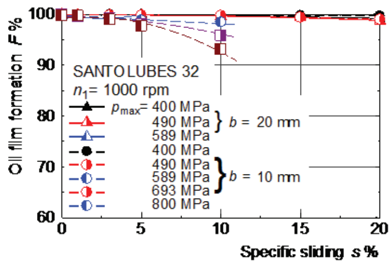



(b) $n_1$=2000 rpm

**Fig. 5 Relations between oil film formation and specific sliding (TD22)**




(a) TD22




(b) SANTOLUBES32

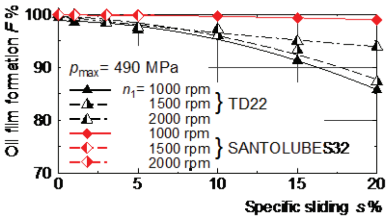
**Fig. 6 Relations between oil film formation and specific sliding ($n_1$= 1000 rpm)**

### 3.2 Roller surface temperatures

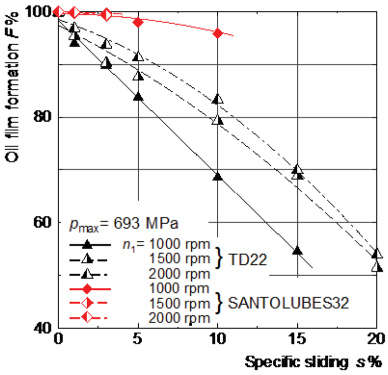
**Figure 8** shows simultaneously measured results of transmitted torque, specific sliding and roller surface temperature for TD22. These curves were obtained for $p_{max}$=693 MPa as specific sliding $s$ from 0 to 15 % under constant speed of the convex roller ($n_1$=1000 rpm). The transmitted torque $T$ increases with increasing $s$ and reaches the maximum value near $s$=5%. Though the increase of $T$ ceases for $s$≥5%, the roller surface temperature continues to increase

**Figure 9** shows the relation between roller surface temperature $\theta_{RS}$ and $s$ for SANTLUBES32 and TD22 under various $p_{max}$ and $n_1$=1000rpm. It is seen from **Fig. 9** that $\theta_{RS}$ increases with increasing $s$, $p_{max}$ and $b$.

**Figure 10** shows the relation between $\theta_{RS}$ and $s$ for SANTLUBES32 and TD22 under various $n_1$ and $p_{max}$= 490, 693MPa. $\theta_{RS}$ of SANTOLUBES32 are larger than those of TD22 irrespective of running condition.




(a) $p_{max}$=490 MPa




(b) $p_{max}$=693 MPa

**Fig. 7 Relations between oil film formation and specific sliding (*b*=10 mm)**

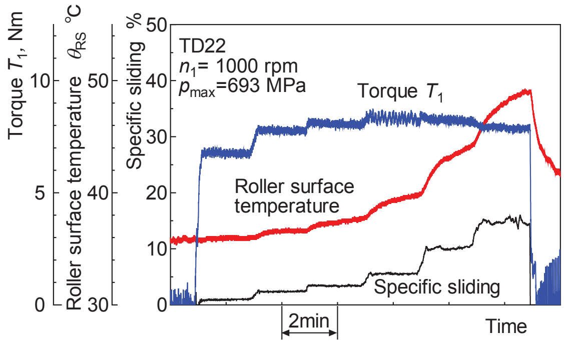
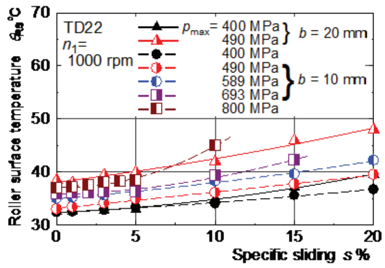
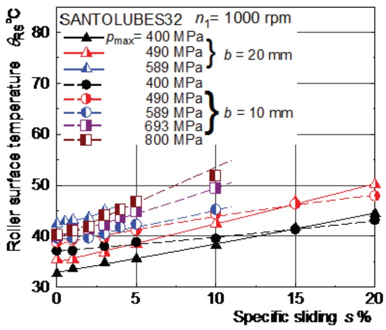



**Fig. 8 Simultaneously measured results of transmitted torque, specific sliding and roller surface temperature (TD22)**

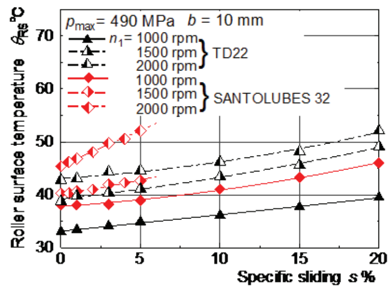



(a) TD22

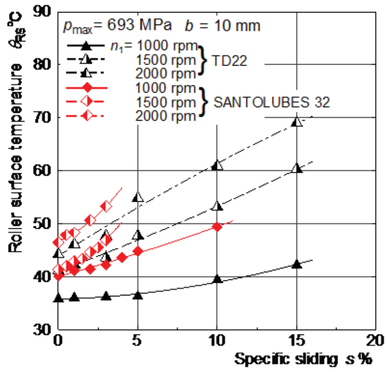



(b) SANTOLUBES32

**Fig. 9 Relations between roller surface temperature and specific sliding ($n_1$= 1000 rpm)**




(a) $p_{max}$= 490 MPa




(b) $p_{max}$= 693 MPa

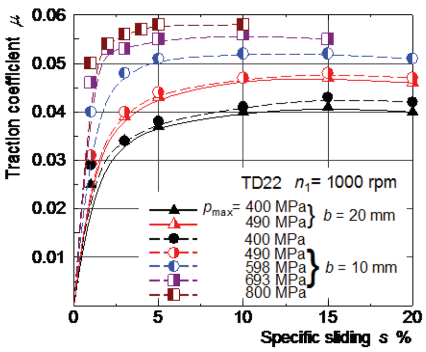
**Fig. 10 Relations between roller surface temperature and specific sliding (*b*= 10 mm)**

### 3.3 Traction coefficients

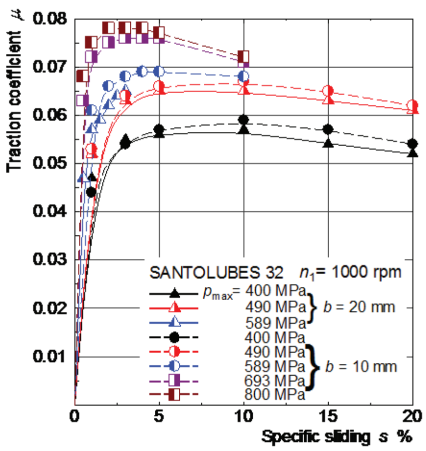
**Figure 11** shows traction curves (relation between traction coefficient $\mu$ and $s$) for TD22 and SANTOLUBES32 under $n_1$=1000rpm and various $p_{max}$. It is seen from **Fig.11** that $\mu$ increases with increasing $s$ in the range of small $s$, reaches to the maximum value at a certain $s$ and decreases gradually. $\mu$ increases with increaseing $p_{max}$ and $b$.

**Figure 12** shows traction curves for TD22 and SANTOLUBES32 under various $n_1$ and $p_{max}$=450, 693 MPa. $\mu$ of SANTLUBES32 are much larger than those of TD22.

**Figure 13** shows comparisons between the maximum traction coefficients $\mu_{max}$ of TD22 and SANTOLUBES32 obtained from traction curves. It is seen from **Fig. 13** that $\mu_{max}$ increases with increasing $p_{max}$ and decreasing $n_1$, and that $\mu_{max}$ of SANTLUBES32 are much larger than those of TD22. $\mu_{max}$ of SANTOLUBES32 and TD22 obtained in this experiment are 0.078 and 0.058, respectively.

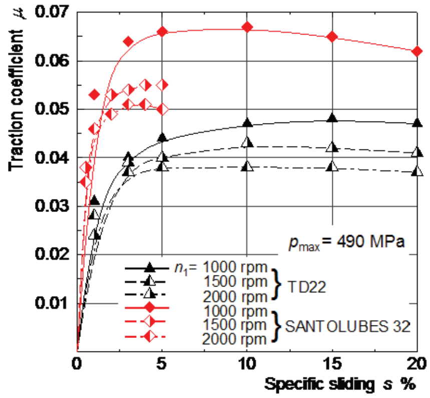



(a) TD22

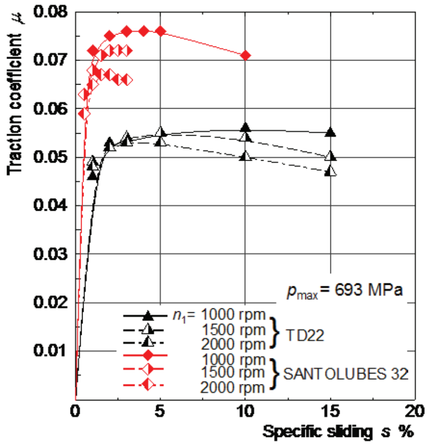



(b) SANTOLUBES32

**Fig. 11 Traction curves ($n_1$=1000 rpm)**




(a) $p_{max}$=490 MPa




(b) $p_{max}$=693 MPa

**Fig. 12 Traction curves ($b$=10 mm)**

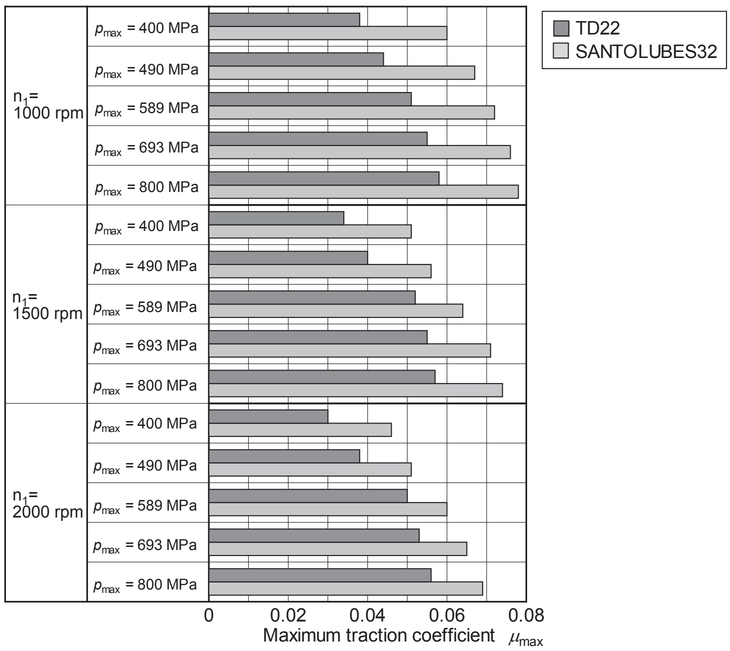



**Fig. 13 Maximum traction coefficients $\mu_{max}$**

## 4 Conclusions

Main results obtained from this investigation are summarised as follows.

(1) The oil film formation $F$ deteriorates with increasing contact pressure $p_{max}$ and specific sliding $s$ and decreasing convex roller speed $n_1$ and contact width $b$. $F$ of SANTOLUBES32 are far superior to those of TD22.

(2) The roller surface temperature $\theta_{RS}$ increases with increasing $s$, $p_{max}$ and $b$. $\theta_{RS}$ of SANTOLUBES-32 are larger than $\theta_{RS}$ of TD22.

(3) The roller surface temperature $\theta_{RS}$ increases with increasing $s$, $p_{max}$ and $b$. $\theta_{RS}$ of SANTOLUBES-32 are larger than $\theta_{RS}$ of TD22.

(4) The maximum traction coefficient $\mu_{max}$ of SANTLUBES32 are much larger than those of TD22. $\mu_{max}$ of SANTOLUBES32 and TD22 obtained in this experiment are 0.078 and 0.058, respectively.

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