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#

Re: Testing of RF85 Treated AISI 52100 Steel Specimens

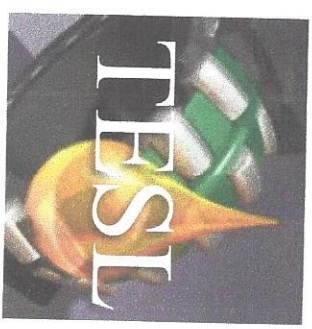
Dear Tom:

Hi Tom,

The report of the testing performed on RF85 treated and untreated AISI 52100 steel specimens has been sent under separate cover to you. As agreed, micro-pitting and scuffing laboratory tests were performed. The RF85 treated specimens outperformed the untreated specimens significantly in the micro-pitting, and RF85 treated bearings were able to achieve more than 34% more cycles to failure than untreated bearings in the scuffing tests. In my opinion, RF85 could provide a significant benefit to the performance of rolling element bearings in many applications. If you have any questions about the results in this report, please do not hesitate to contact me. Based upon our test results, it looks like you have something of value to rolling element bearings in RF85. Congratulations.

Sincerely,

Gary L. Doll, Ph.D., F-ASM, F-STLE
Timken Professor of Surface Engineering



RF85 Project

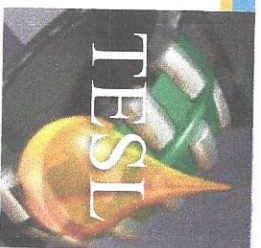
Graduate Student: Haifeng Qin

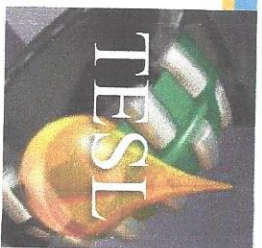
Adviser: Dr. Gary Doll

**Timken Engineered Surfaces Lab (TESL)
The University of Akron
12-09-2016**

Outline

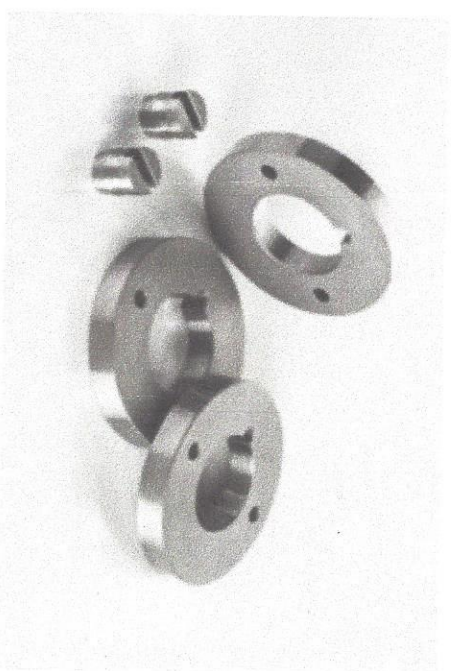
- **Micropitting Tests**
- **Scuffing Tests**
- **Wear Tests**





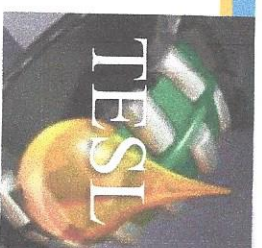
Micropitting Tests

Samples: MPR Rollers



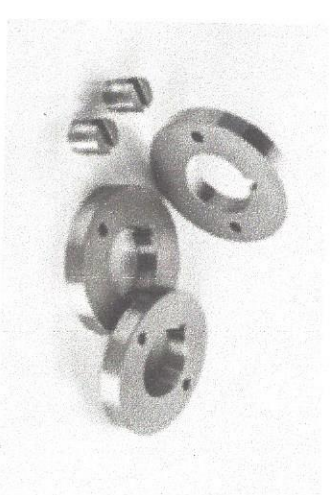
Micropitting Tests

MPPR Test Conditions



Test Condition	
Speed	3.5m/s
SRR	10%
Load	600N (2.0Gpa)
Temperature	40°C
Oil	PAO ISO-10

Test Rollers	
Untreated Rollers	Un-01, Un-02, Un-03
RF85 treated Rollers	Tr-01, Tr-02, Tr-03
Test Rings	
5210 Case Carburized	



Before testing, test samples and cell were cleaned by isopropanol.

After testing, all test Samples were retained for further analysis.

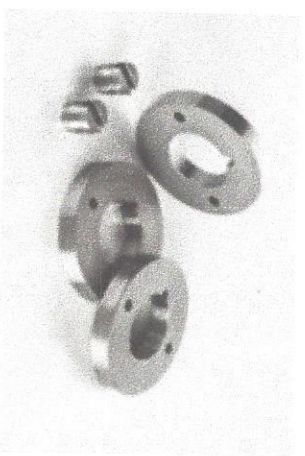
Untreated 5210 case carburized rings were used in all tests.

Micropitting Tests

MPPR Test Specimens



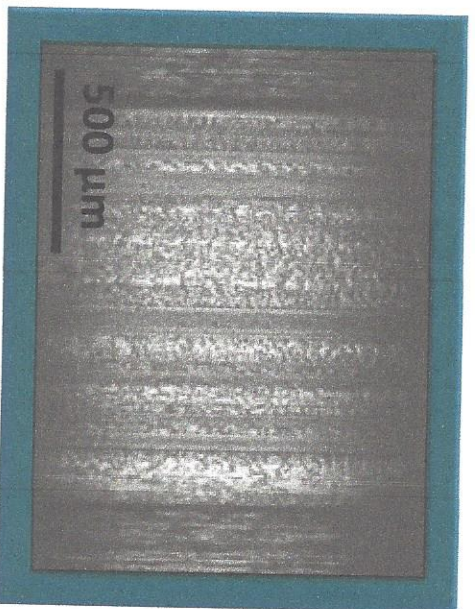
Property	Rings	Untreated Rollers	RF85 Treated Rollers
Material	5210 Case Carburized	52100 Through Hardened	52100 Through Hardened
Hardness	64 HRC	63HRC	63HRC
Surface Roughness	$0.45 \pm 0.2 \mu\text{m}$	$0.14 \pm 0.1 \mu\text{m}$	$0.12 \pm 0.2 \mu\text{m}$



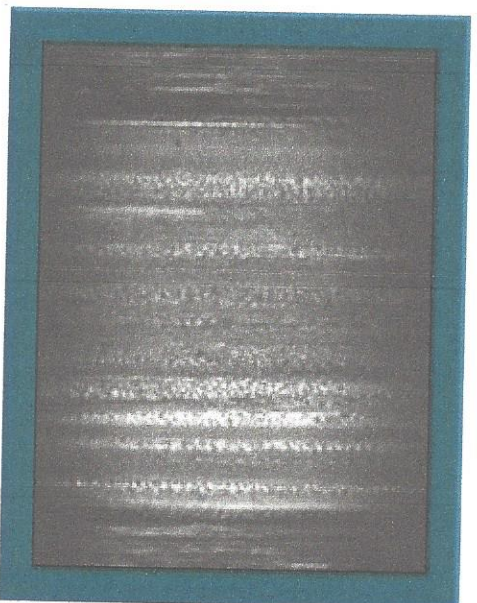
Images of untreated and RF85 treated rollers during the test
After running 0.5×10^6 cycles



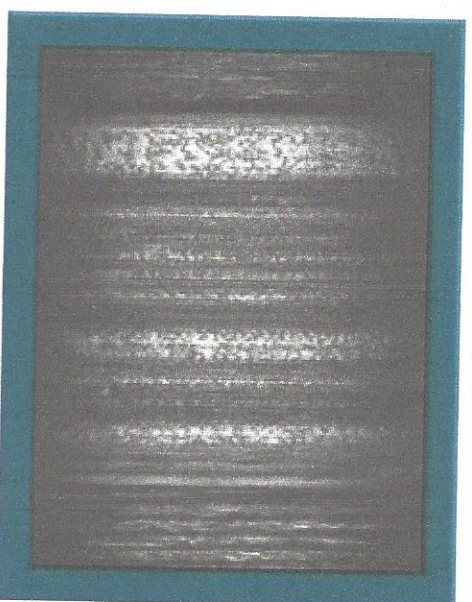
Un-01



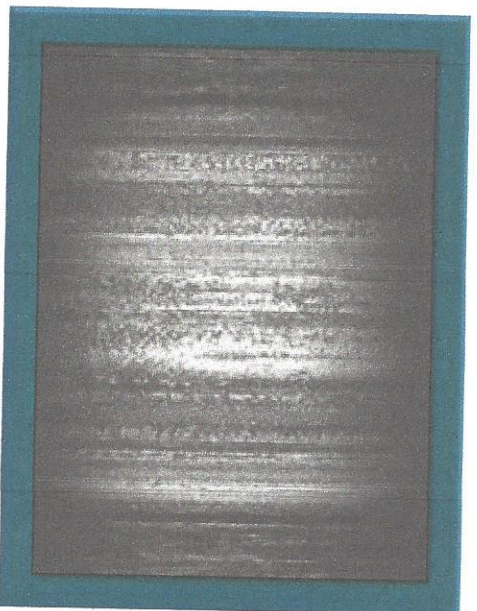
Un-02



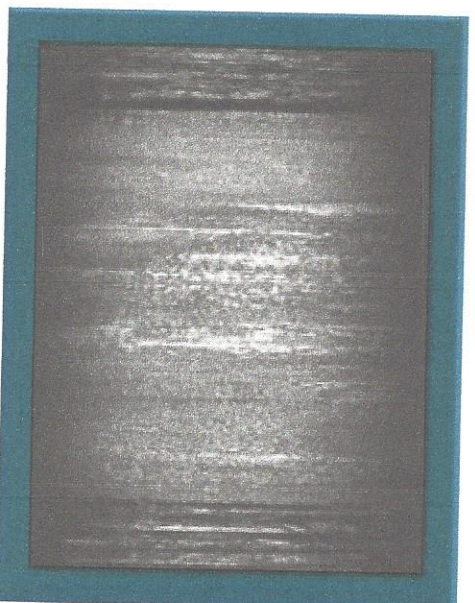
Un-03



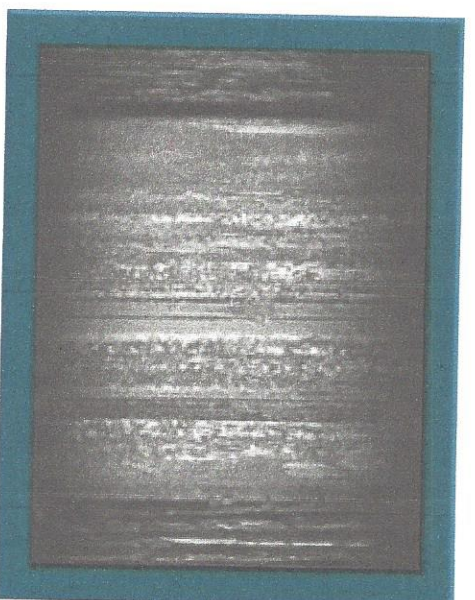
Tr-01



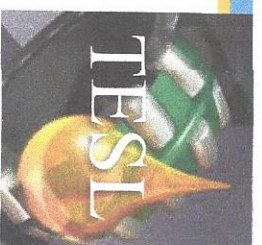
Tr-02



Tr-03



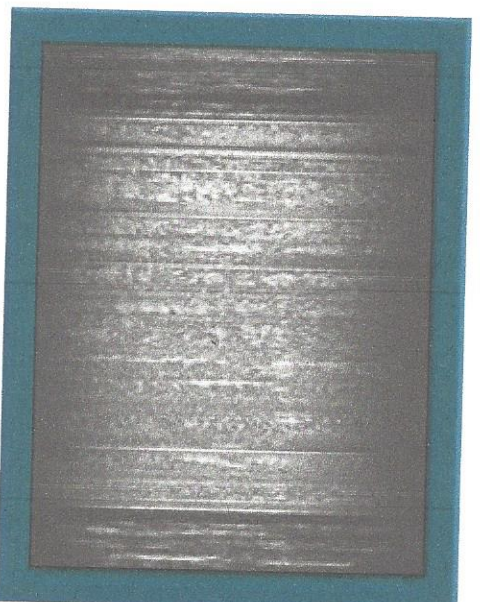
Images of untreated and RF85 treated rollers during the test
After running 1.5×10^6 cycles



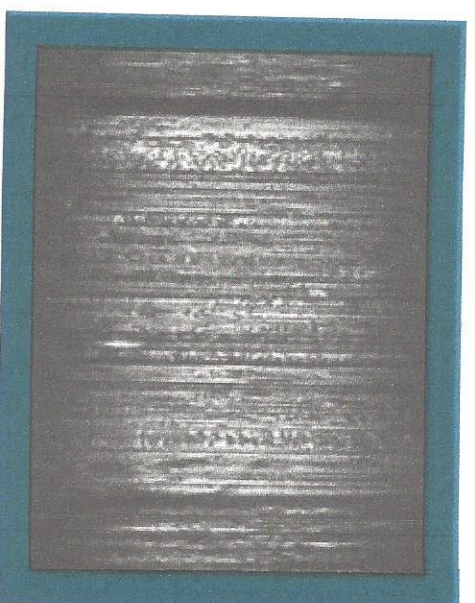
Un-01



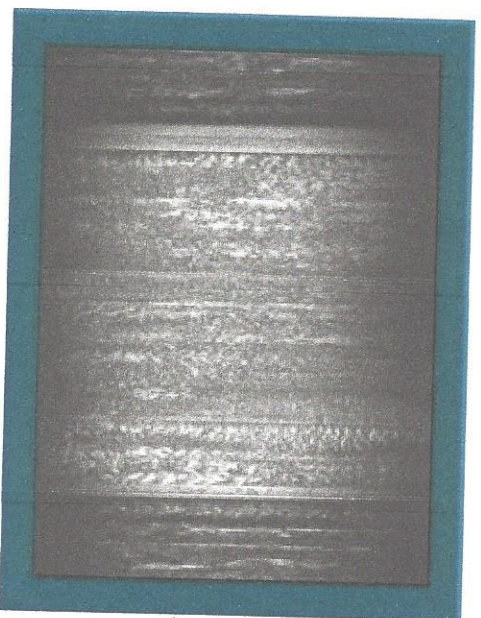
Un-02



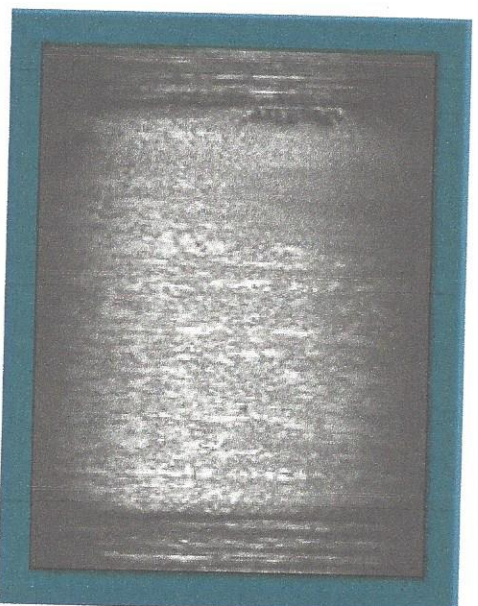
Un-03



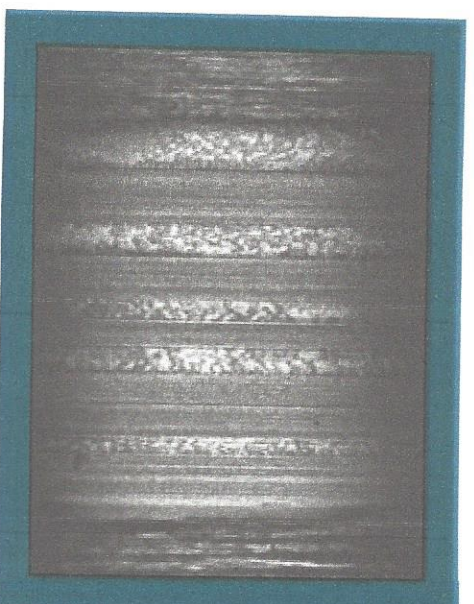
Tr-01



Tr-02



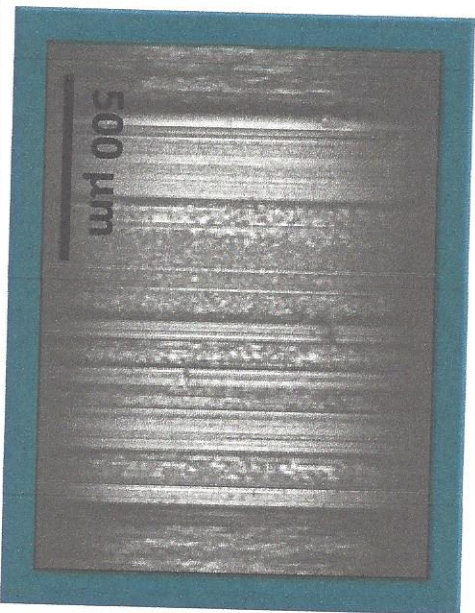
Tr-03



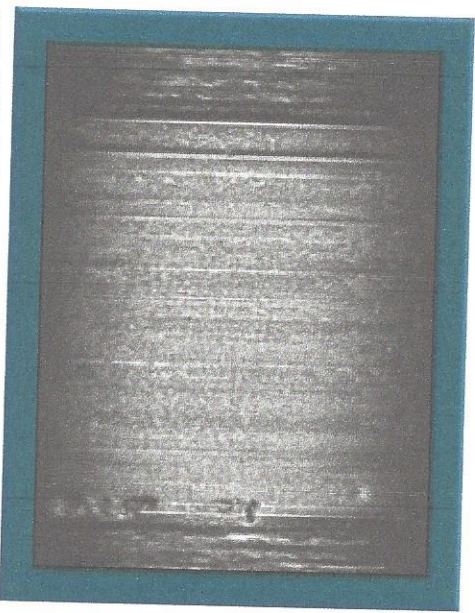
Images of untreated and RF85 treated rollers during the test
After running 2.5 X 10⁶ cycles



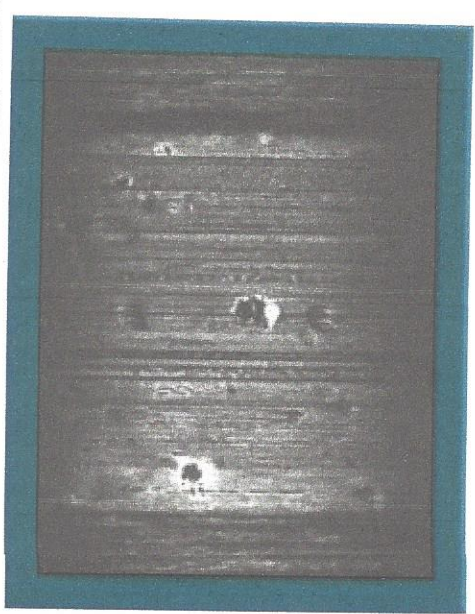
Un-01



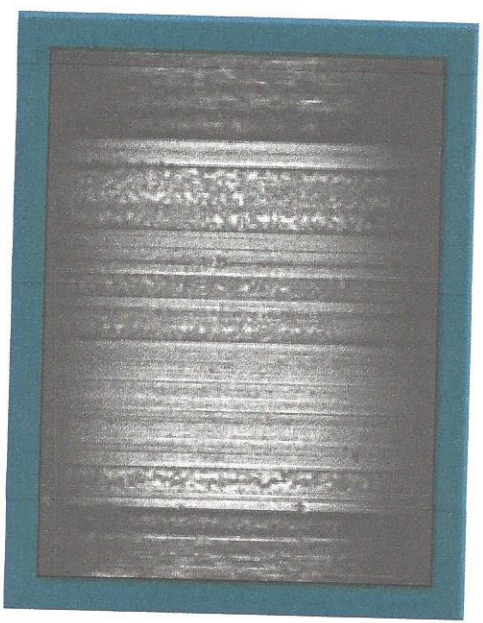
Un-02



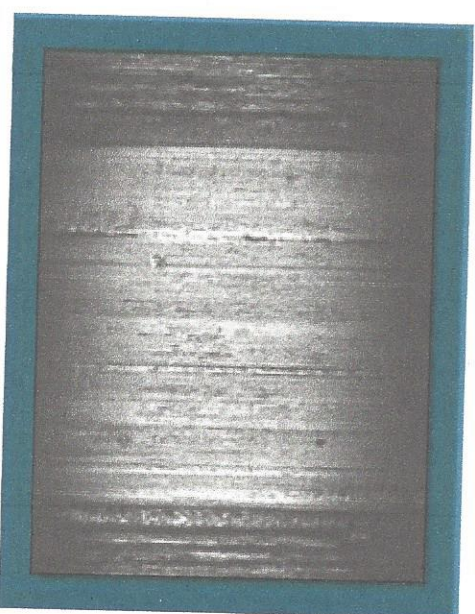
Un-03



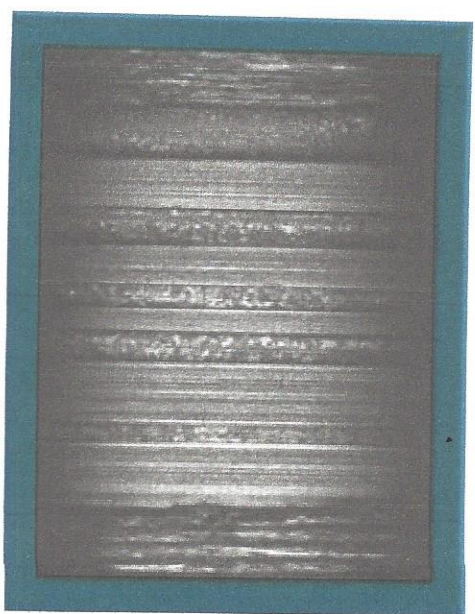
Tr-01



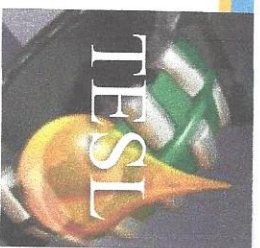
Tr-02



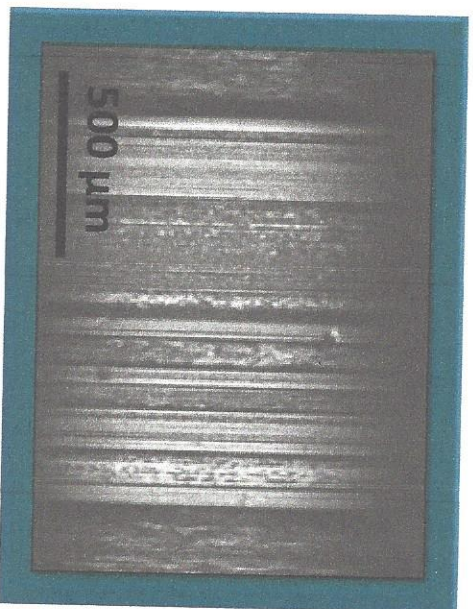
Tr-03



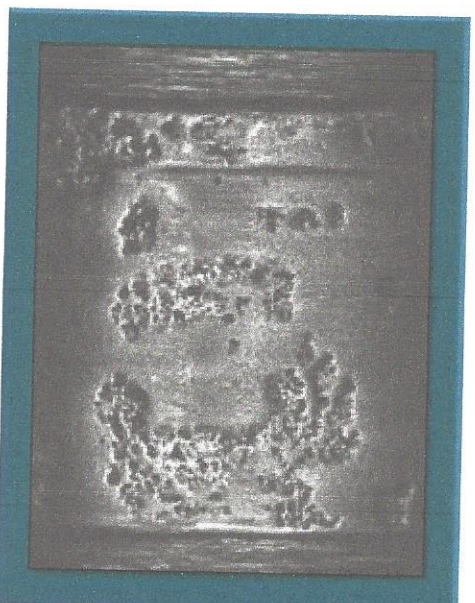
Images of untreated and RF85 treated rollers during the test
After running 3.5×10^6 cycles



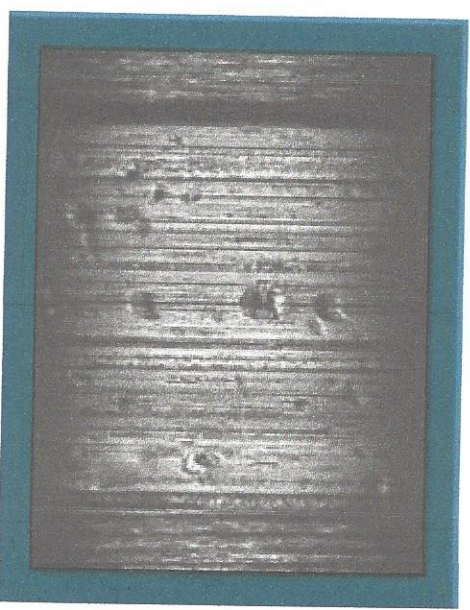
Un-01



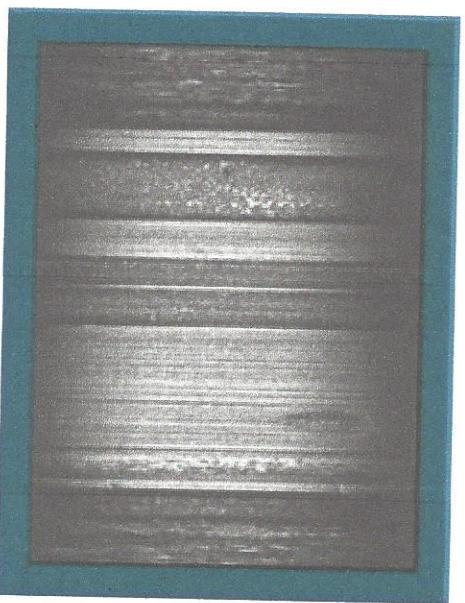
Un-02



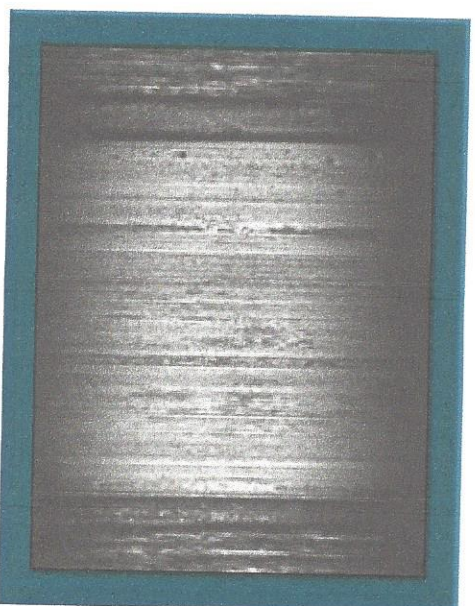
Un-03



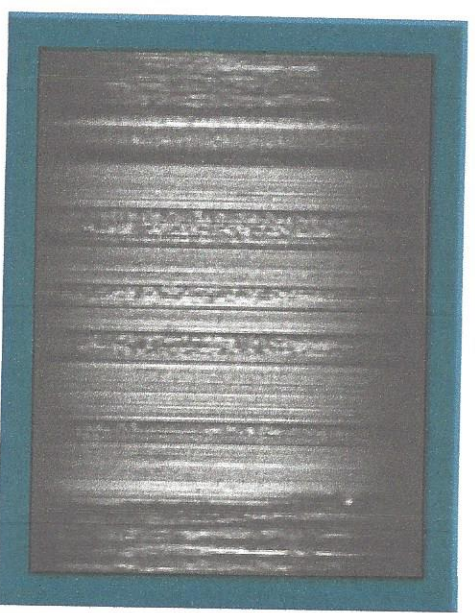
Tr-01



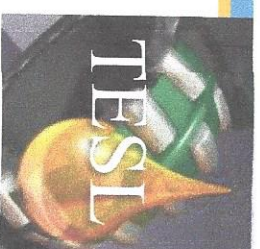
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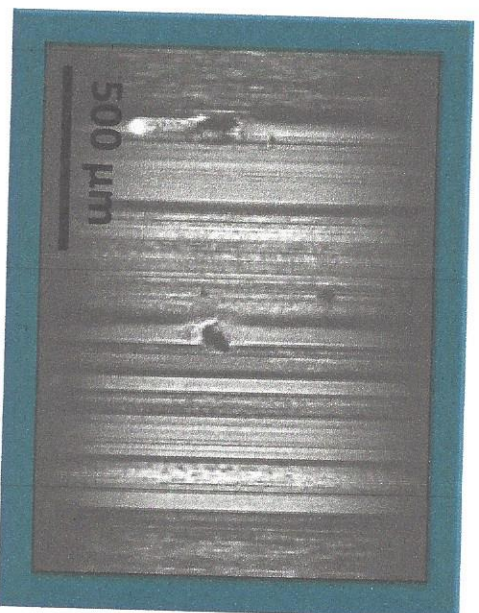
Tr-03



Images of untreated and RF85 treated rollers during the test
After running 5×10^6 cycles



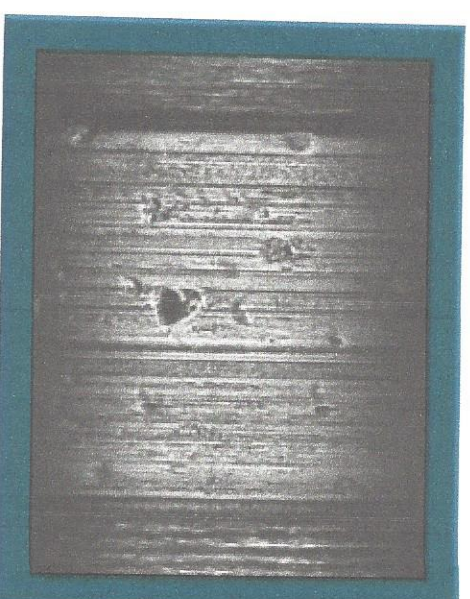
Un-01



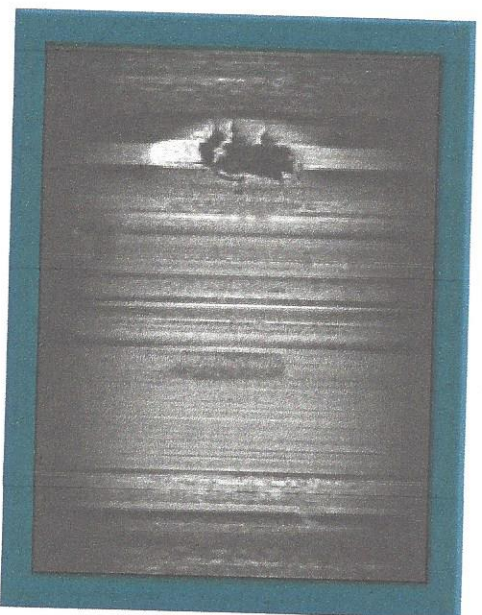
Un-02

End test at
 3.5×10^6 cycles

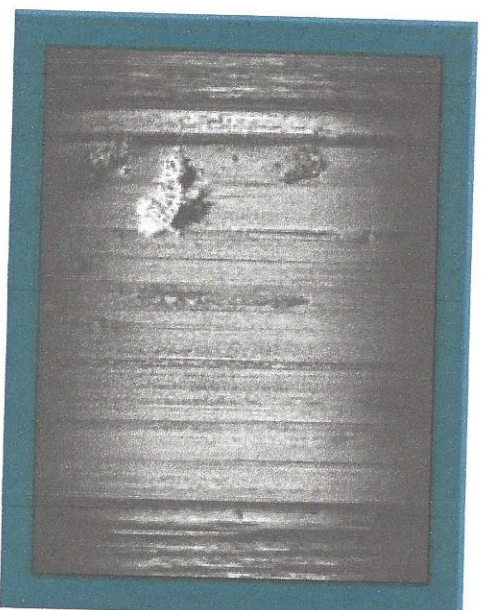
Un-03



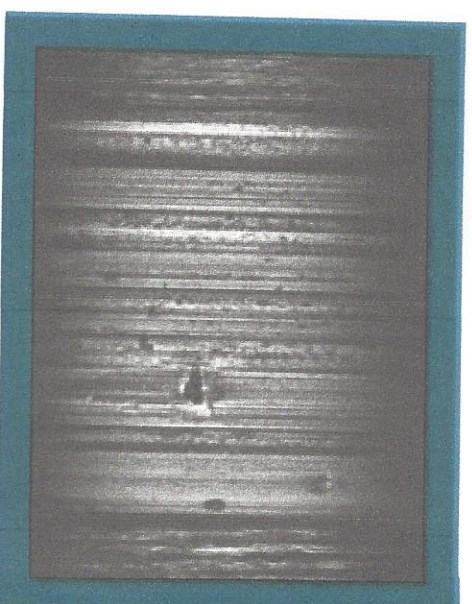
Tr-01



Tr-02



Tr-03

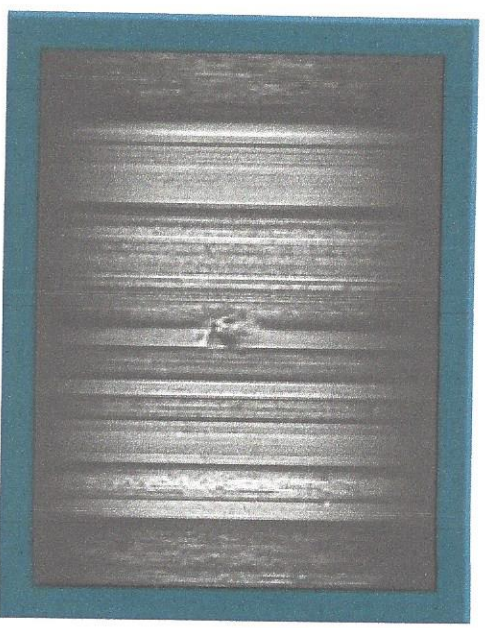
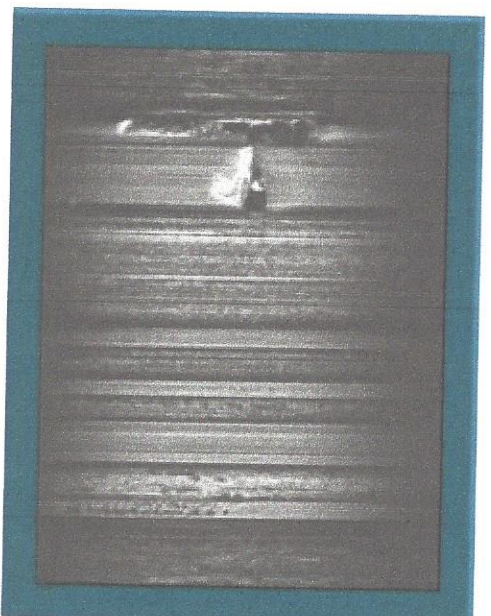
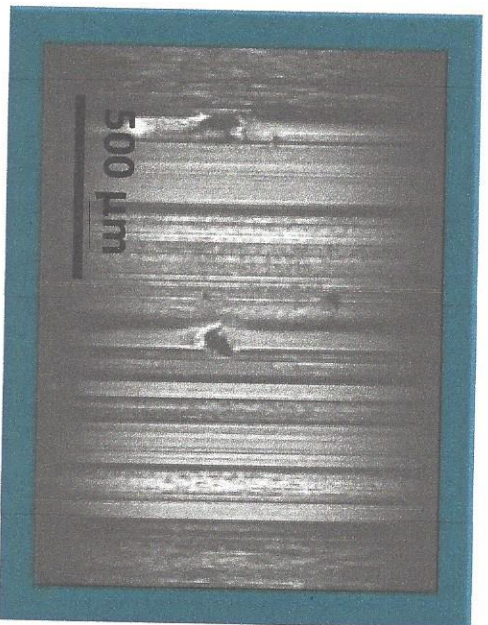


More images of untreated and RF85 treated rollers at end of test (5 X 10⁶ cycles)



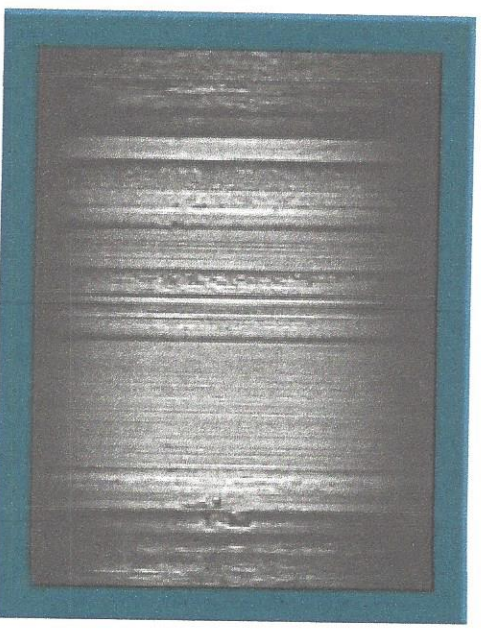
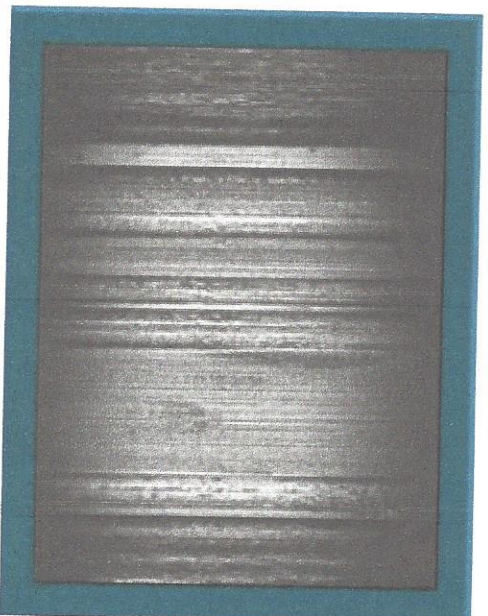
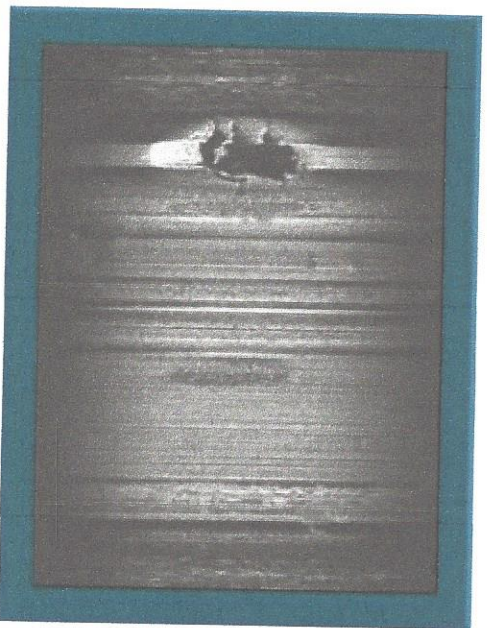
Un-01

Different locations of the same roller

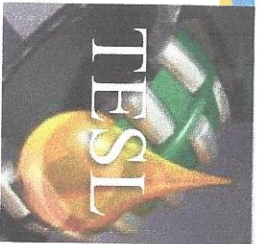


Tr-01

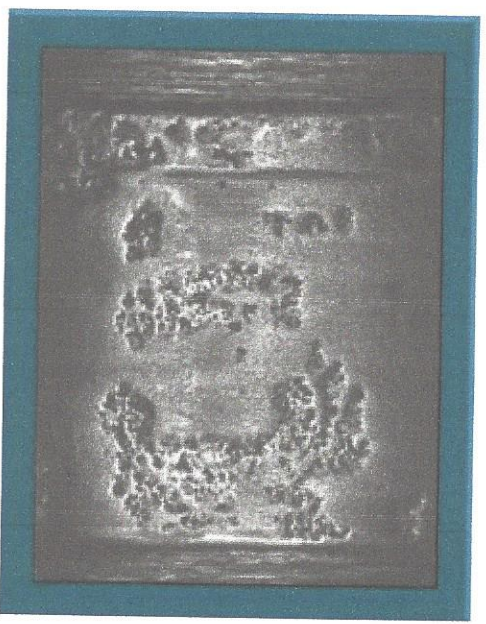
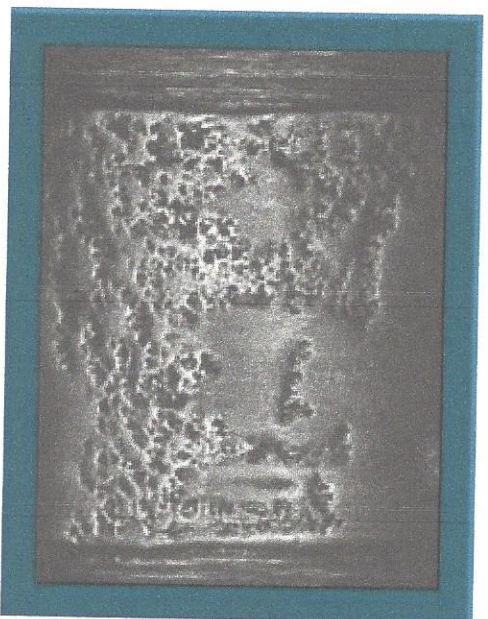
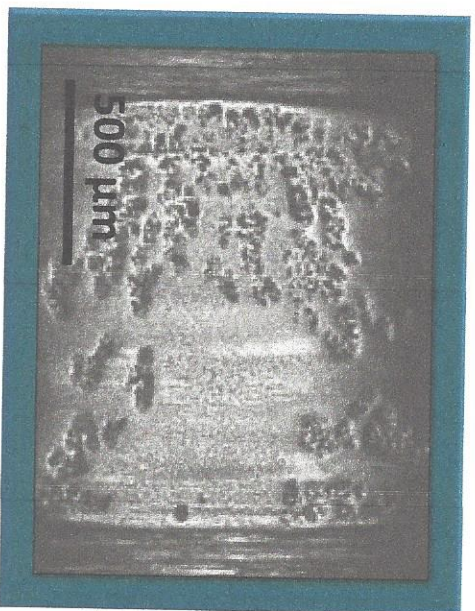
Different locations of the same roller



More images of untreated and RF85 treated rollers at end of test

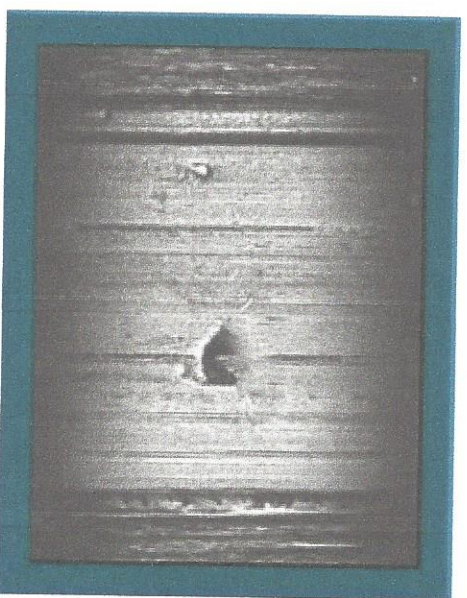
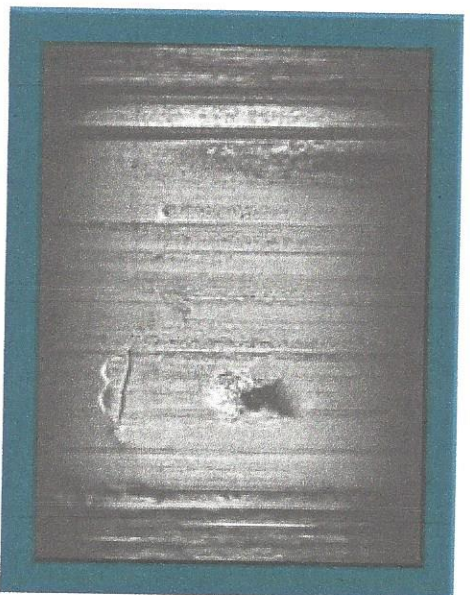
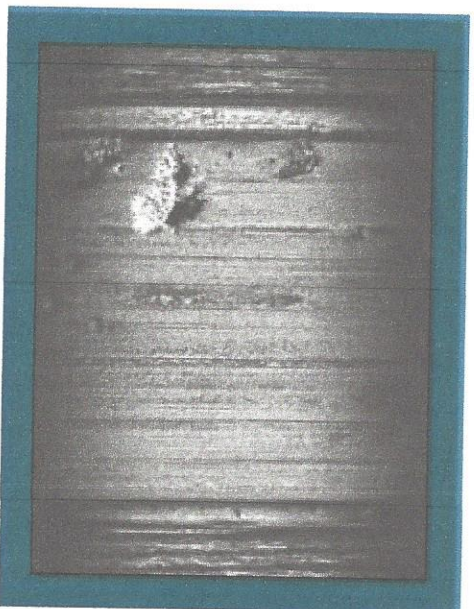


Un-02 (3.5 X 10⁶ cycles) (End the test at 3.5 X 10⁶ cycles because of surface damage)



Tr-02 (5.0 X 10⁶ cycles)

Different locations of the same roller

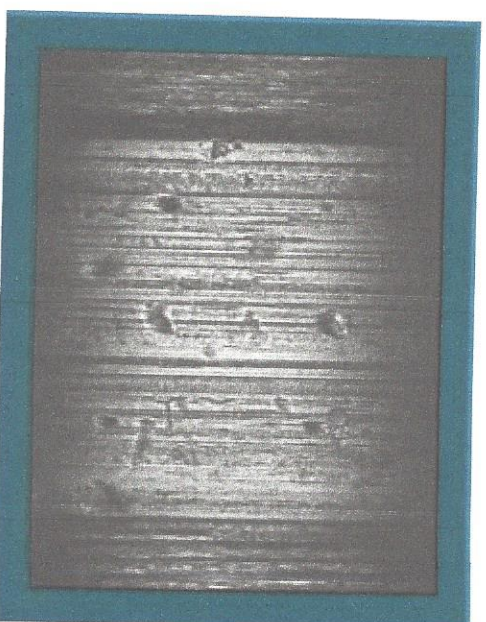
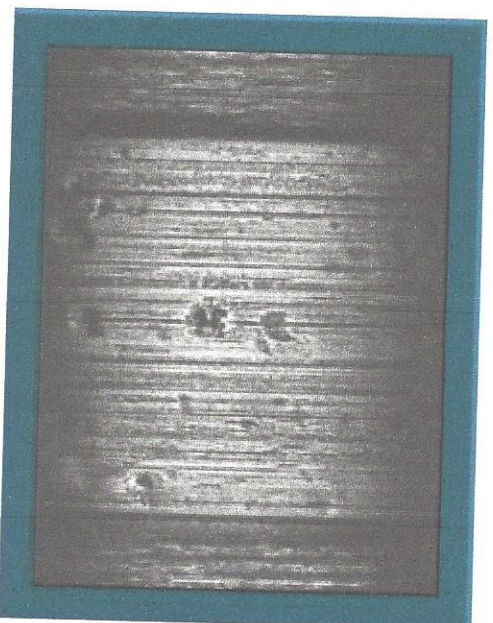
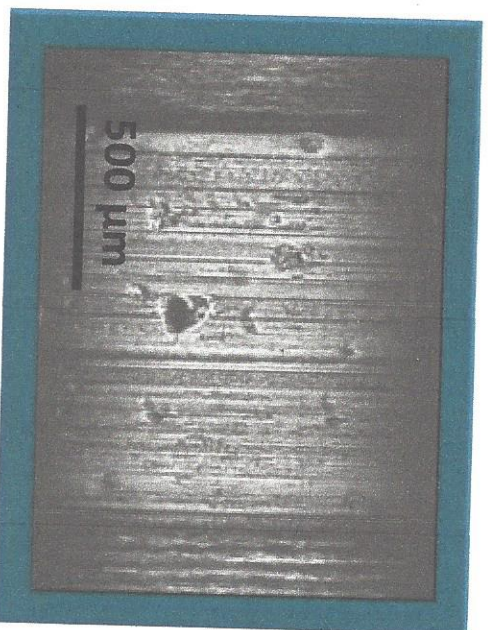


More images of untreated and RF85 treated rollers at end of test (5 X 10⁶ cycles)



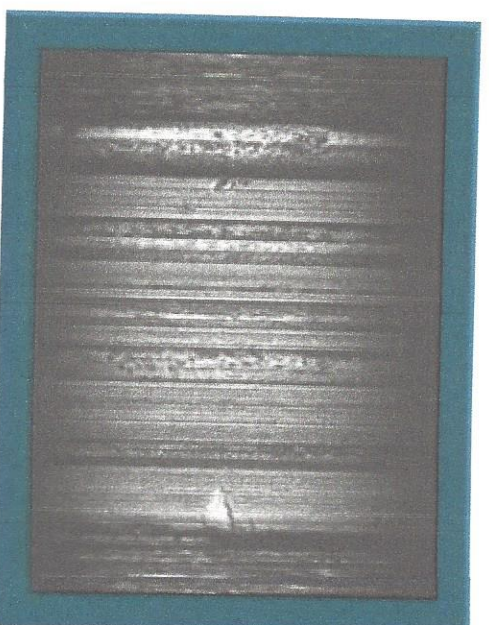
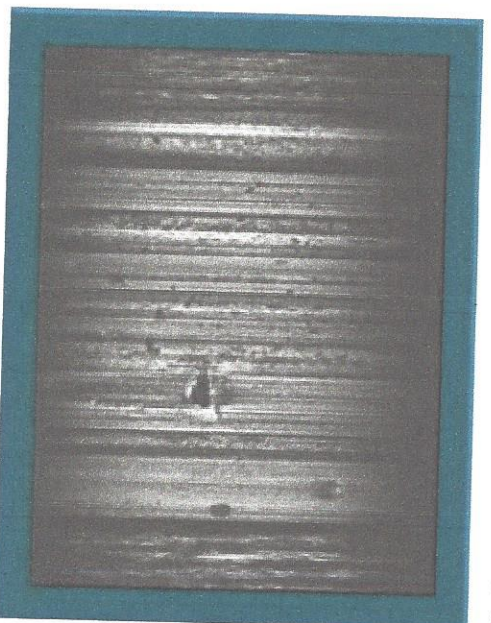
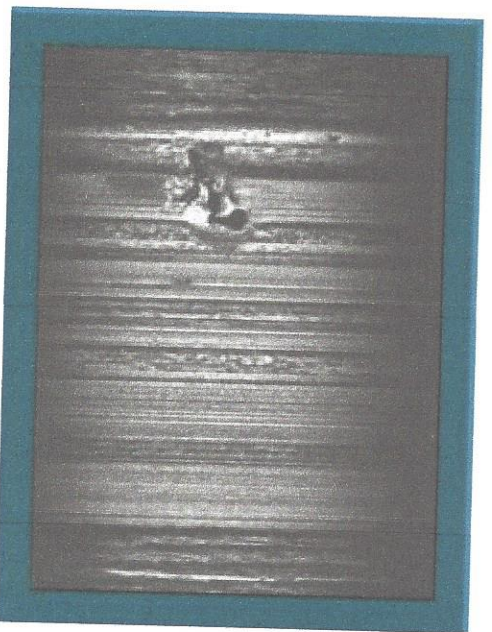
Un-03

Different locations of the same roller

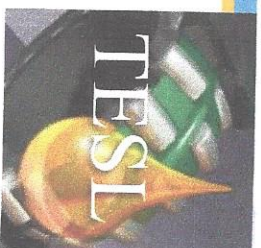


Tr-03

Different locations of the same roller



Summary of the condition of rollers surface during the tests

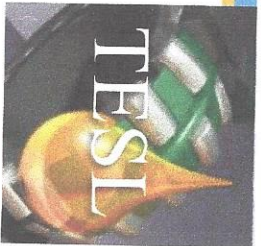


Tests	0.5 X 10 ⁶ cycles	1.5 X 10 ⁶ cycles	2.5 X 10 ⁶ cycles	3.5 X 10 ⁶ cycles	5.0 X 10 ⁶ cycles
Un-01	None	None	None	MC	ME MC
Un-02	None	None	ME	ME MC	N/A
Un-03	None	None	ME MC	ME MC	ME MC
Tr-01	None	None	None	None	ME
Tr-02	None	None	None	None	ME MC
Tr-03	None	None	None	None	ME MC

ME: Micropit at the edge of raceway

MC: Micropit in the raceway

Micropitting resistance was improved by RF85 treatment.



Scuffing Tests

Samples: Thrust ball bearings (51306)



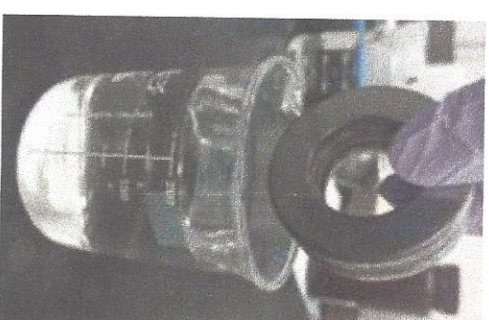
Scuffing Tests

Thrust Ball Bearing (51306) Test Conditions

Test Condition	
Revolving speed	1200 RPM
Load	1320 lbf (5872N)
Running Time	Until the torque reaches to 200 Ounce-Inches (1.4 Newton-Meter)
Starting temperature	21 °C ± 1°C (Room temperature)
Test Bearings	
Untreated bearing	Un-01, Un-02, Un-03, Un-04, Un-05
RF85 treated bearing	Tr-01, Tr-02, Tr-03, Tr-04, Tr-05



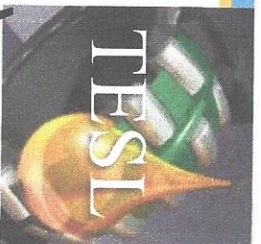
Before testing, test bearings and cell were cleaned by isopropanol.



Immerse the bearing in the solution **(5% PAO ISO 10 oil + 95% Heptane)** for 10s. Then, let it dry 20min in room temperature.



**Images of untreated and RF85 treated thrust bearing (51306)
after scuffing test**



Un-01 (1.35h)



Un-02 (0.67h)



Un-03 (1.18h)



Tr-01 (1.29h)



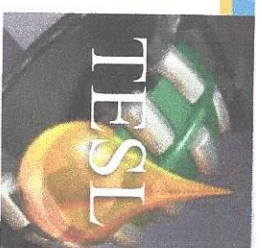
Tr-02 (1.28h)



Tr-03 (1.6h)



Images of untreated and RF85 treated thrust bearing (51306) after scuffing test



Un-04 (1h)



Un-05 (0.83h)



Tr-04 (1.1h)



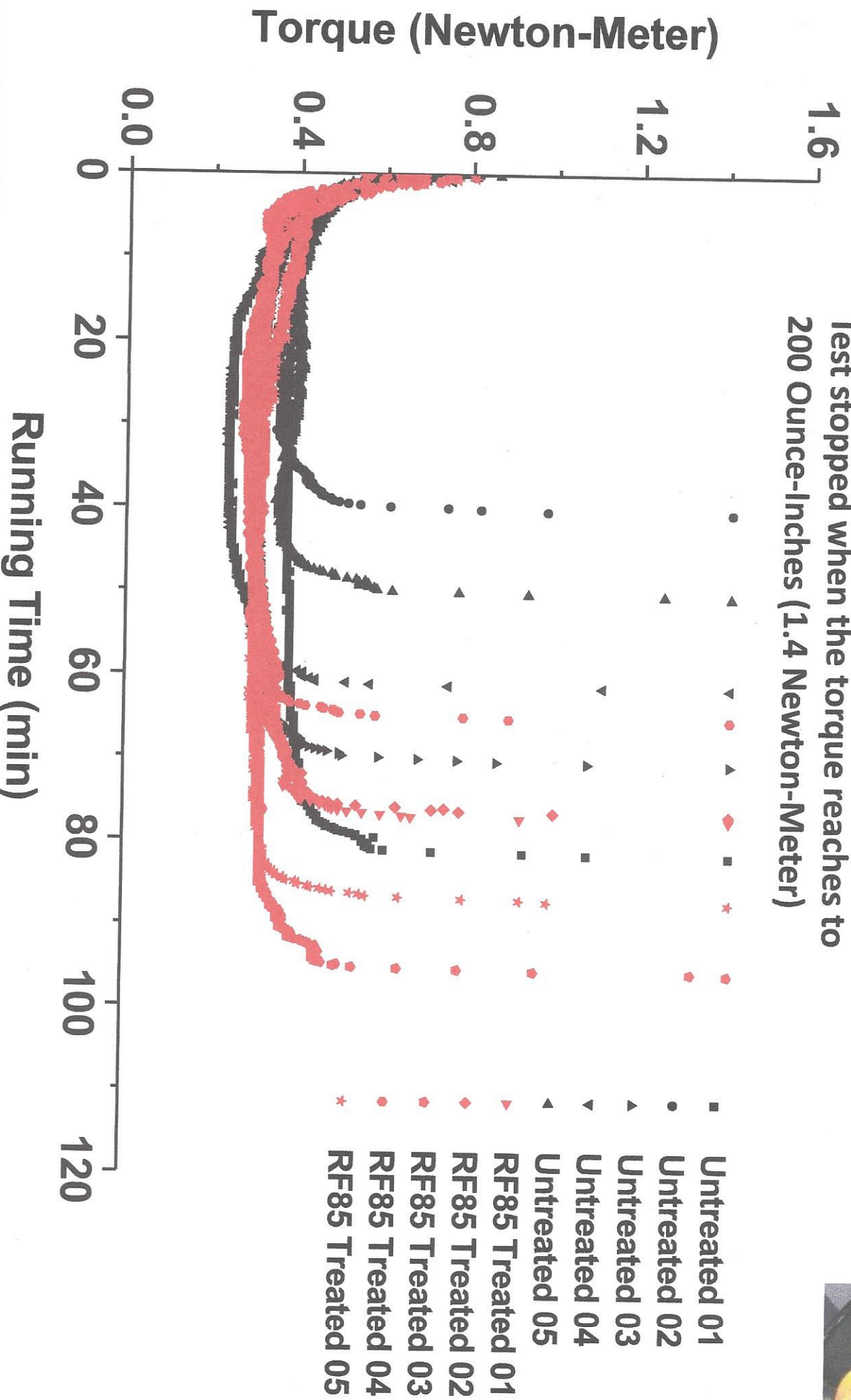
Tr-05 (1.5h)



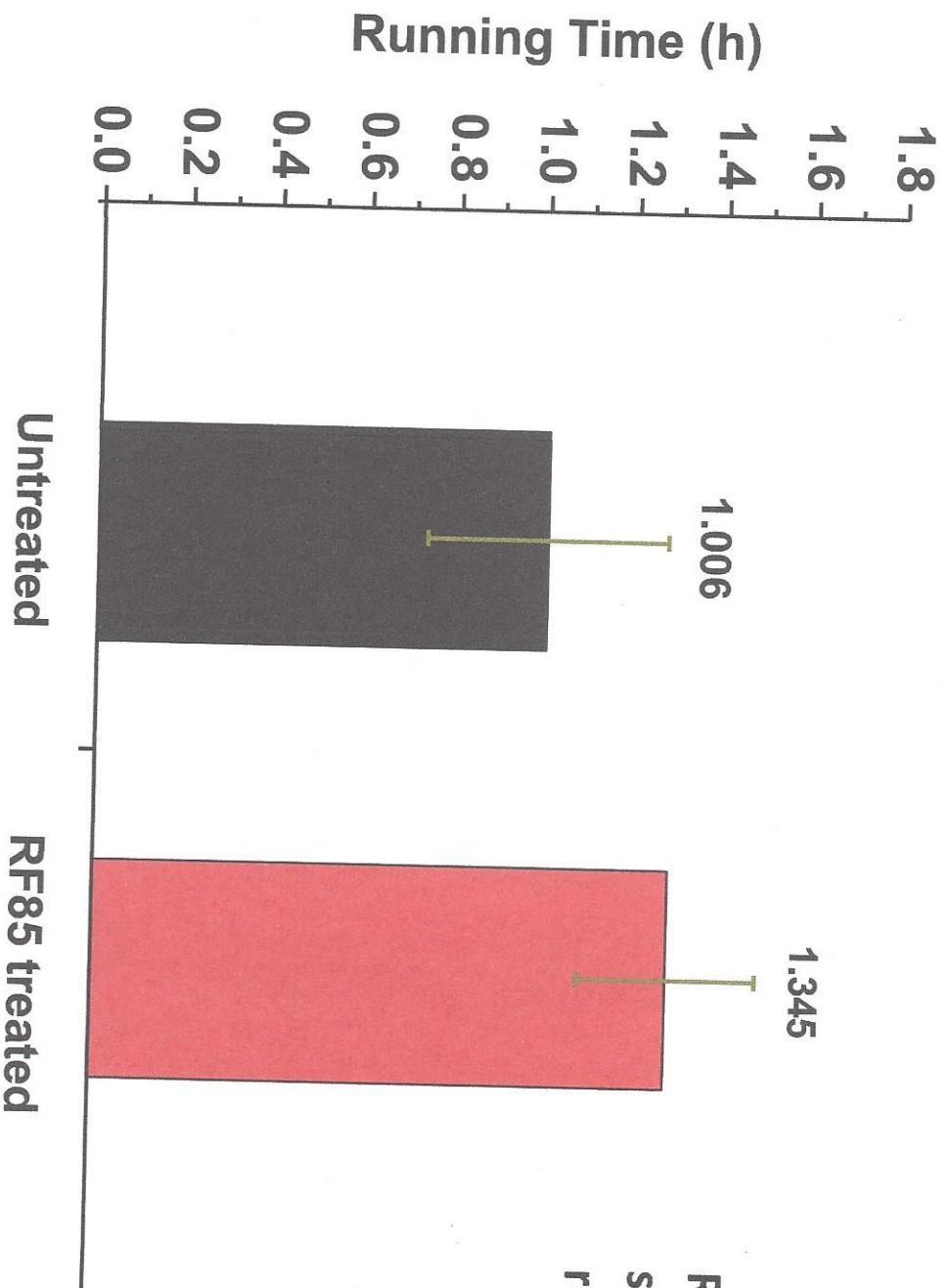
Torque VS. Running Time



Test stopped when the torque reaches to 200 Ounce-Inches (1.4 Newton-Meter)

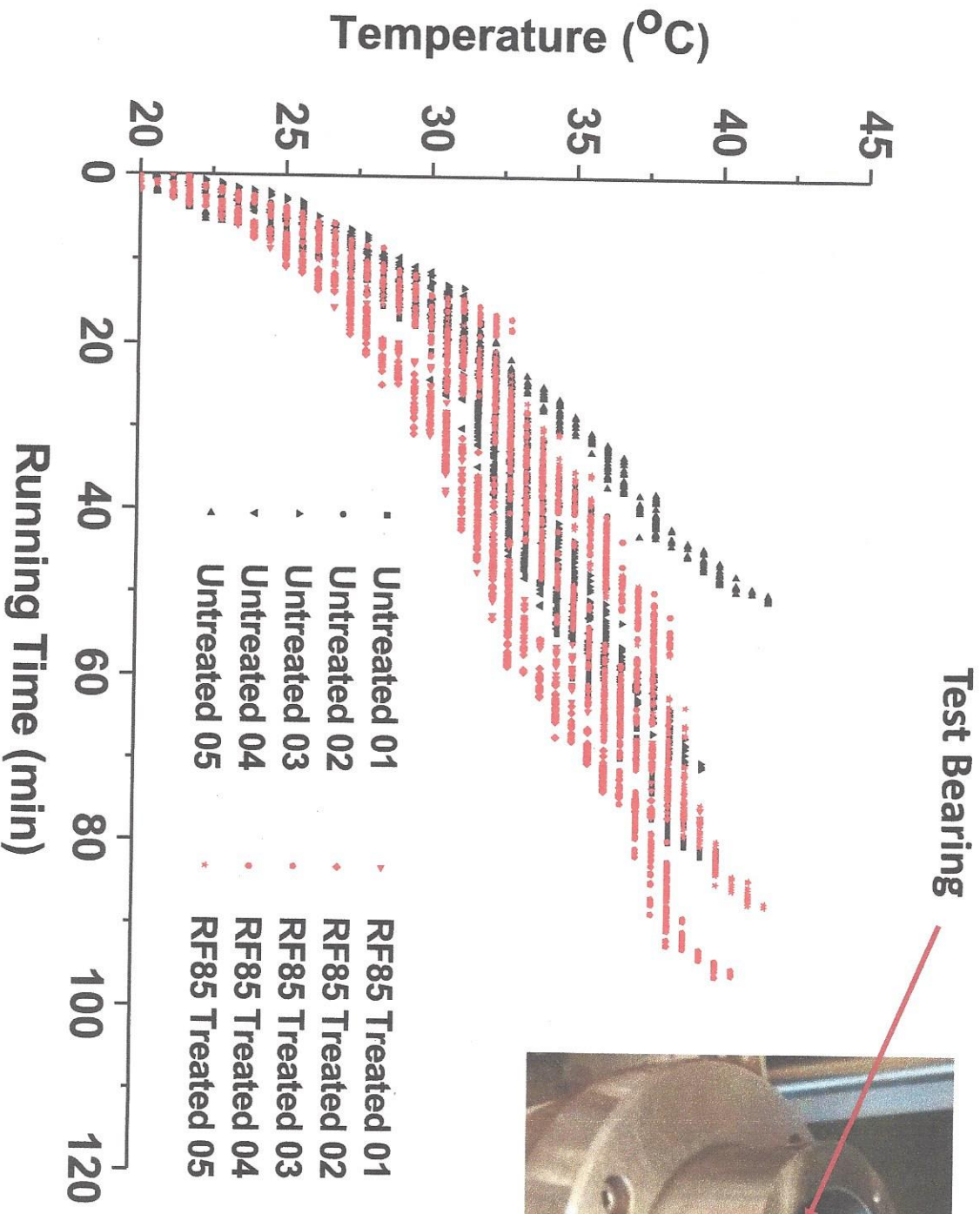
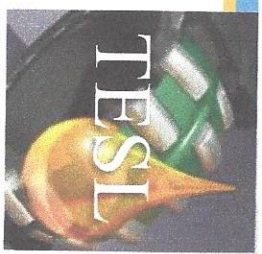


Running time for the torque reaches to 200 Ounce-Inches (1.4 Newton-Meter)



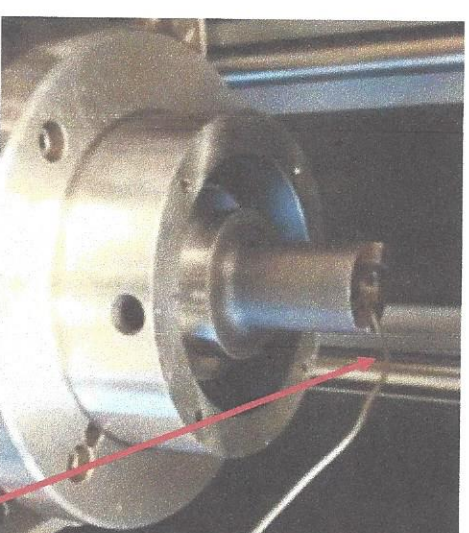
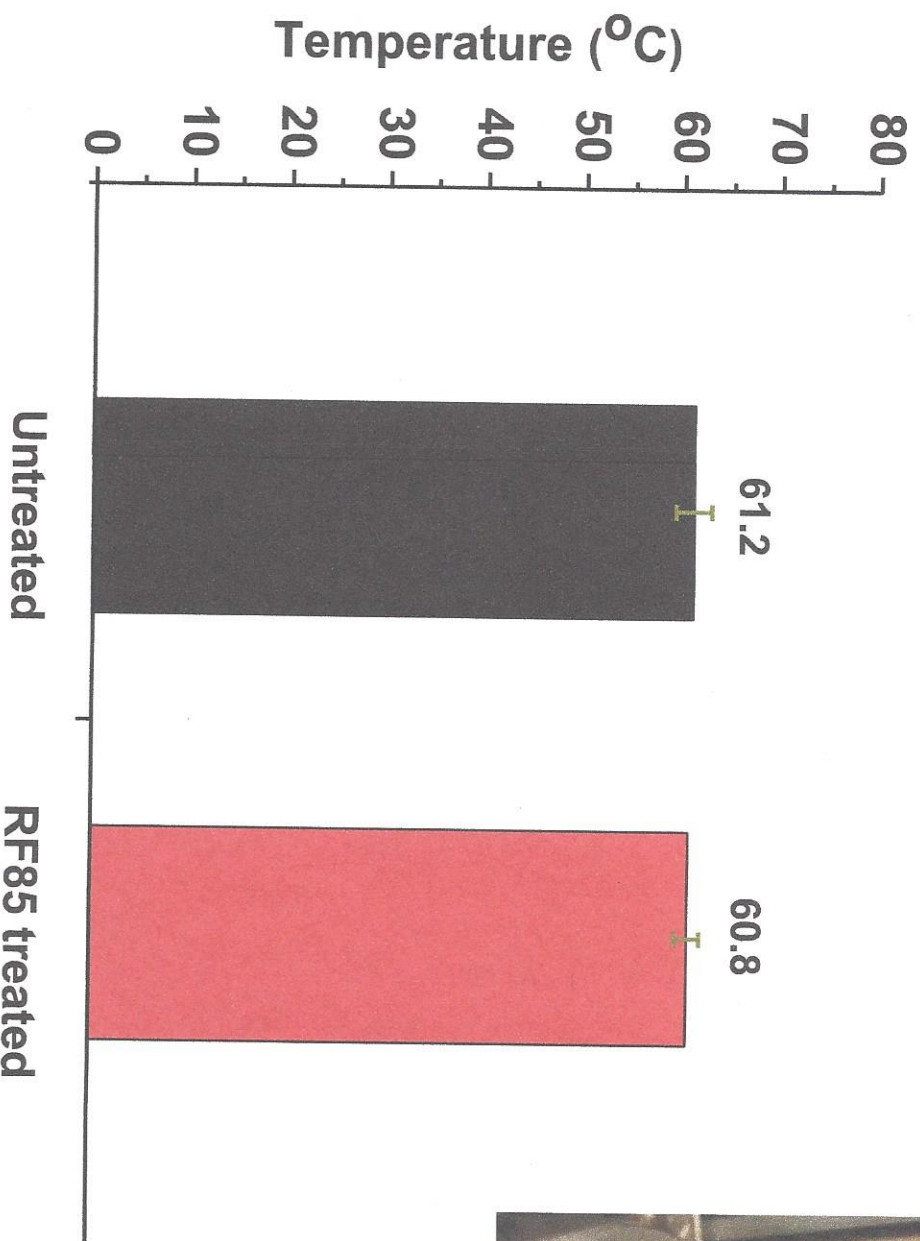
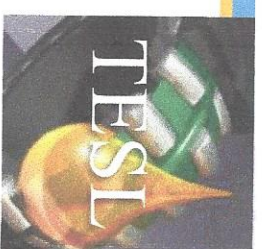
RF85 Treated bearing showed ~34% longer running time.

Bearing Holder Temperature VS. Running Time

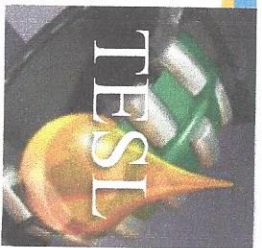


Thermocouple
measures *in situ*
temperature

Inside Temperature at the End of Tests



Thermocouple
measures
inside
temperature
after each test

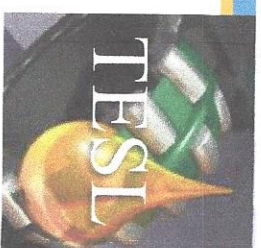


Wear Tests

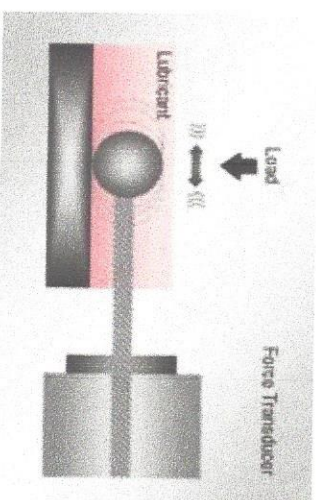
Samples: PCS HFRR 52100 disk and 52100 ball



HFRR Test Conditions



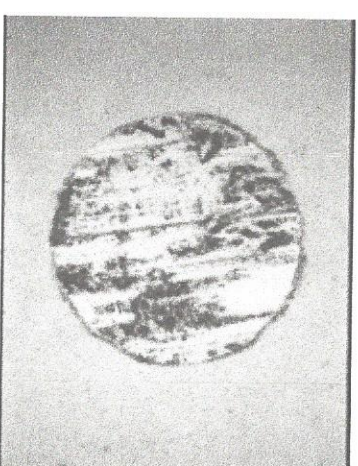
Parameter	
Temperature	25 °C
Humidity	40%-45%RH
Load	2 N
Frequency	20 Hz
Stroke length	1000 µm
Run time	1, 2, 5, 10, 15, 20 min



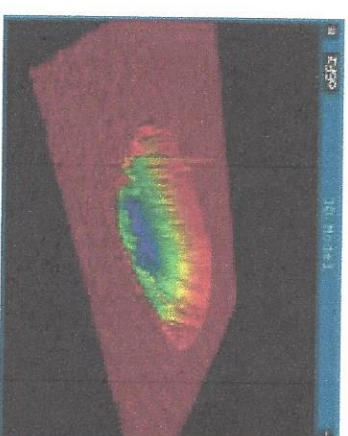
Test Samples

Untreated 52100 Disk with Untreated 52100 Ball

RF85 Treated 52100 Disk with RF85 Treated 52100 Ball

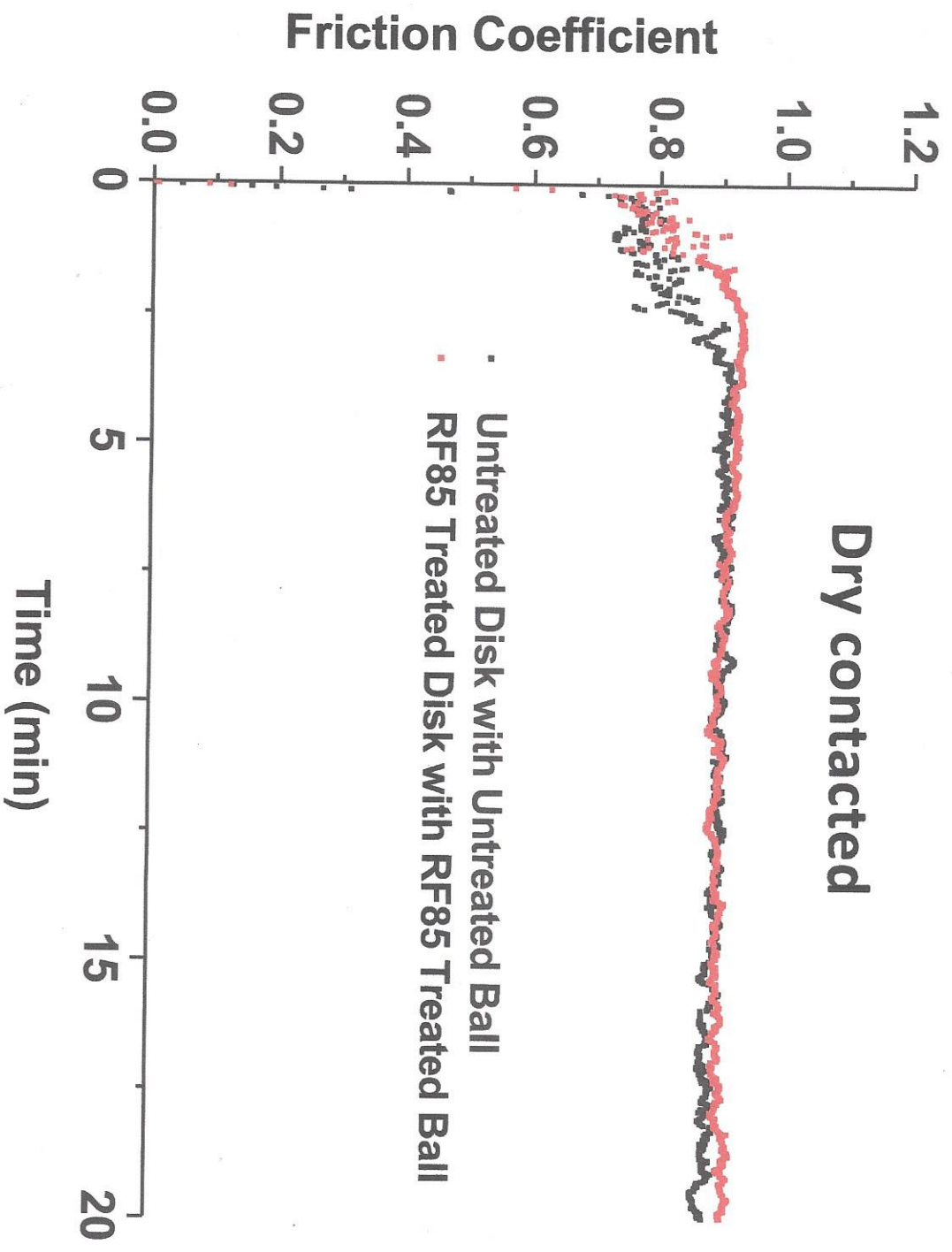
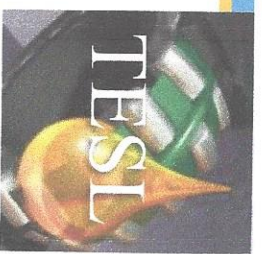


Ball's wear volume was calculated by diameter of wear scar.



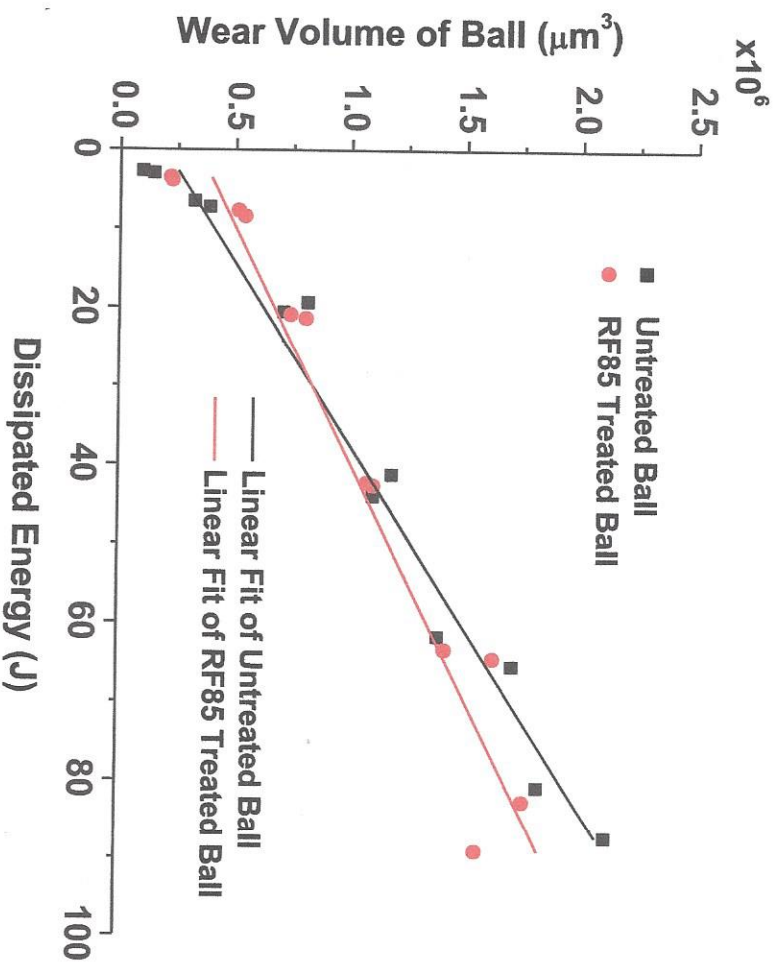
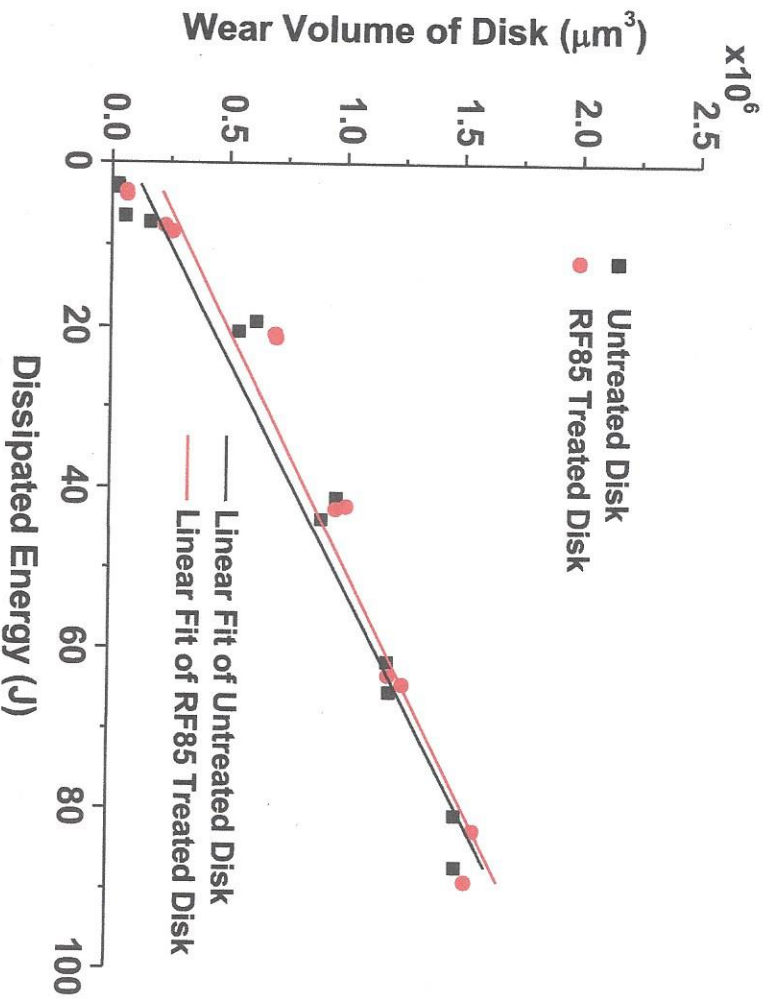
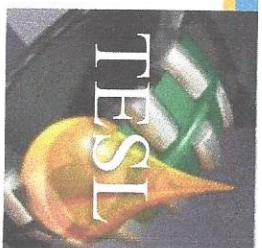
Disk's wear volume was measured by Zygo New View 7300.

Coefficient of Friction VS. Running Time



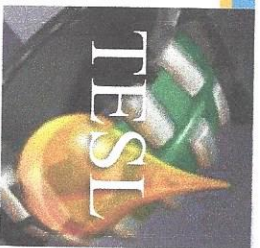
Similar friction coefficient.

Wear Volume VS. Dissipated Energy



Similar wear rate.

Summary



- Tests for micropitting were performed on a PCS MPR test rig using standard protocol to create micropitting in the rollers. RF85 treatments improved the resistance to micropitting of the AISI 52100 bearing steel rollers.
- RF85 treatments increased the scuffing onset time of AISI 52100 thrust roller bearings by about 34%
- RF85 treatments on AISI 52100 test specimens did not alter the friction and wear performance in reciprocating sliding contact over untreated specimens