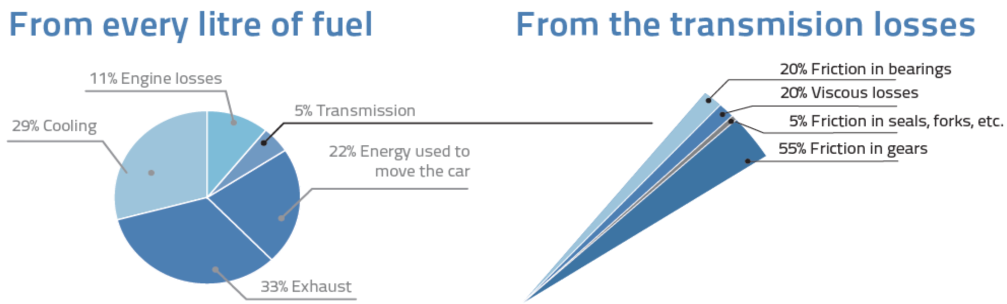
Enhancement of Tribological Behavior of ZrCN Coating

1st Coatings and Interfaces Web Conference

CONTENT

1. Introduction

- Roller bearings → for rotating applications, particularly in automotive industry
- Bearing losses:



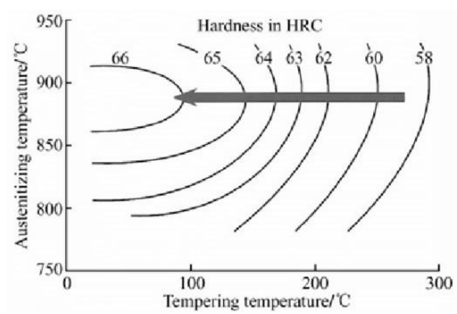
- Bearings characteristics:
  - Low friction in lubricated conditions (friction coefficient < 0.05)
  - Line contact between the roller and the outer and inner rings
  - Contact pressures may vary from 0.5 up to 3 GPa
  - The rolling operation abides by the elastohydrodynamic (EHD) theory
- Nowadays, tribology → reduce friction → reduce fuel consumption
- Methods for reducing friction on bearings:
  - Updating internal bearing geometry
  - Changing bearing component materials
  - New lubricants development
  - **Coating rolling bearing surface**
    - Properties can be infinitely varied and combined without implying a complete change of the original conception of mechanical components → low-cost approach

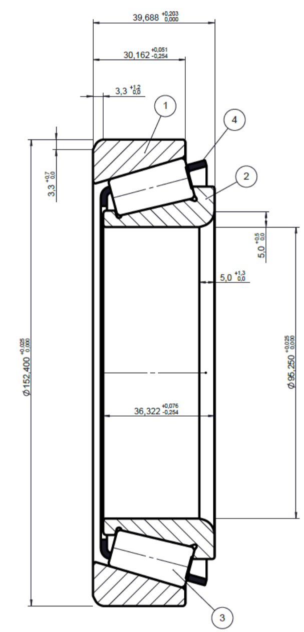
2.1. **Materials.** Substrate

- Bearing steel 100Cr6 (according to ISO 683/17) has been used as PVD substrate.

Mass Fraction [%]											
C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**O**	**Al**	**Ti**	**Ca**
0,93-1,05	0,15-0,35	0,25-1,20	0,025	0,015	0,90-1,60	0,10	0,25	10-15 ppm	0,050	30-50 ppm	10 ppm

- Due to endurance strength, distribution must compensate equivalent stress level → steel heat treated (martensitic through hardening) → surface hardness to 59–63 HRC
- Therefore, substrate temperature was very important to maintain surface hardness





- Tapered roller bearing part number:
  - 594A/592A belonging to TRB inches family from FERSA BEARINGS S.A.
  - Used in differential application in heavy duty

2.2. Materials. Coating layer

- Materials used for coating layer creation are:
  - Zr target, purity R60702, ≥99.5% weight; from Robeko (Šibenik, Croatia)
  - Ti target, purity grade 2, 99.5% weight; from Robeko (Šibenik, Croatia)
  - Reactive gases
    - Hydrogen in Argon (20%)
    - Alphagaz 2 Argon (purity ≥ 99.9999 mol %)
    - Alphagaz 2 Nitrogen (purity ≥ 99.9999 mol %)
    - Alphagaz 1 Acetylene (purity ≥ 99.6 mol %) from Air Liquide (Paris, France)

3.1. Experimental. Physic Vapor Deposition

1. Cleaning Process

Sample substrates are cleaned under a degreasing-solvent sequence

→

Samples loaded in the vacuum chamber which is evacuated up to a pressure of 10−4 mbar

→

Glow Discharge cleanliness stage applying a voltage under vacuum conditions in an atmosphere of Ar+H2

→

A high negative bias of −600V is applied then decreased progressively up to −30 V

2. PVD Process

- Cathodic Arc Evaporation (CAE) method to deposit titanium-zirconium-based coatings.
- CAE method:
  a) Applying hundred volts between an anode and in presence of argon gas in a vacuum chamber → melting or evaporating tiny quantities of material.
     Approximately 90 % of the evaporated cathode particles form positively charged metal ions.
  b) A bias voltage is applied between the vacuum chamber and the substrate → metal ions accelerated in the direction of the sample surface.
  c) A reaction between metal ions and a reactive gases → deposition of the ions on the sample as a fine CN layer.

The process is carried out with an industrial equipment MIDAS 775:

- Vacuum chamber volume Ø750mm2x750 mm
- 12 circular arc evaporators (ø100 mm) in four columns;
- 45 kW pulsed DC bias power supply system up to 1000V
- working intensity range of 60–200 A
- maximum temperature substrates of 500ºC
- N_2, C_2H_2, O_2 reactive gases.

3.1. Experimental. Physic Vapor Deposition

4 different PVD processes have been developed using 4 metallic evaporators (2 Ti, 2 Zr), and introducing Nitrogen gas (N_2) and acetylene (C_2H_2) :

Coating design	Deposition time (min)					Layer configuration	Resistance temperature (ºC)
	Layer composition	Ti	Ti-Zr	TiN	Ti-Zr-N		
D1	Ti + Ti-Zr	60	5	0	0	ZrCN multilayer	250
D2	Ti + Ti-Zr	5	1	0	0	ZrCN multilayer	250
D3	Ti + TiN + Ti-Zr-N	1	0	4	1	ZrCN multilayer	250
D4	Ti + Ti-Zr	60	5	0	0	ZrCN multilayer + ZrN bilayer	250

2 different methods polishing post-process have been carried out:

- Method A:
  - Uses walnut shell as abrasive in an OTEC DF 35 machine (a)
  - Procedure: applying 30 minutes steps (15 minutes each way) at 20 rpm

(a)

- Method B
  - Uses walnut shell additivated with a silica base abrasive (80%) in a Pardus Drag Finish Unit from PD2i machine
  - Procedure: applying 15 minutes (1.5 min each way) at 35 rpm

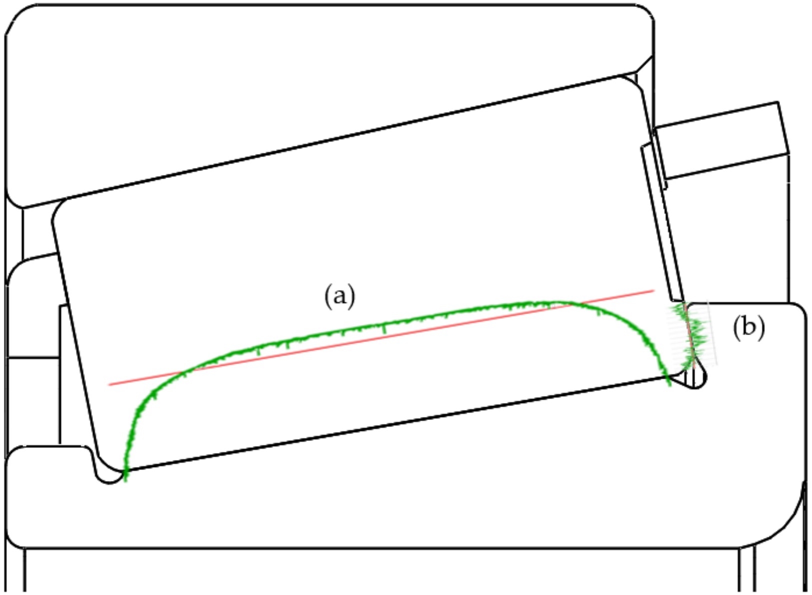
(b)

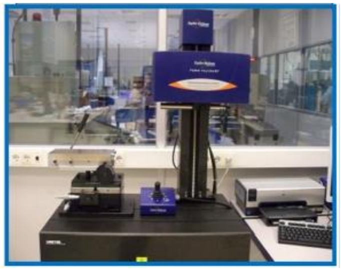
Configuration	Method	Time (min)	Rotate Speed (rpm)
A1	A	180	20
A2	A	360	20
B	B	15	35

3.3. Experimental. Geometrical analysis

Before testing coating quality parameters, a complete metrological analysis was done for bearing raceway (a) and flange (b) including:

- **Profile characterization** using a Form Talysurf 120. This analysis is crucial to know if coated bearing samples to be tested are comparable to baseline design bearing according to allowed limits and shapes agreed by FERSA BEARINGS SA..
- **Roundness of raceway** according to ISO 1101 [31] with a Talyrond 365 with software Ultra by Taylor Hobson V5.21.9.36.





Talysurf 120

Talyrond 365

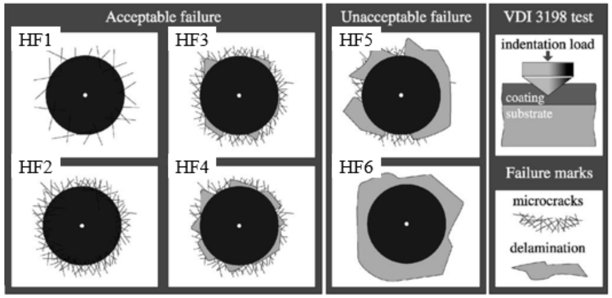
3.4. Experimental. Coating properties

- **Roughness**
  - Ra (arithmetical mean deviation of the assessed profile) is measured
  - Perthometer M2 from Mahr
  - Quantification is made by measuring vertical deviations of a real surface comparing to its ideal shape.
  - R_a must be lower than 0.15 µm according to FERSA BEARINGS SA know-how.

- **Thickness**
  - Coating thickness has been determined by means of a calostest test with a Calotest CSEM equipment
  - A ball is turned over the coating until it arrives to substrate producing a spherical crater
  - Microscope measuring of this dimple diameter → coating thickness
  - Adequate thickness measurement range is between 1 and 10 µm because for smaller thickness dimple could be too small leading to inaccurate measurements

3.4. Experimental. Coating properties

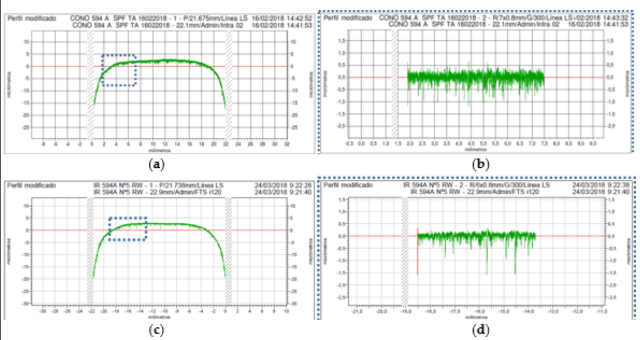
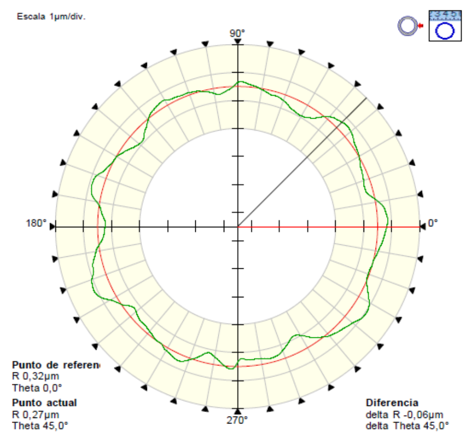
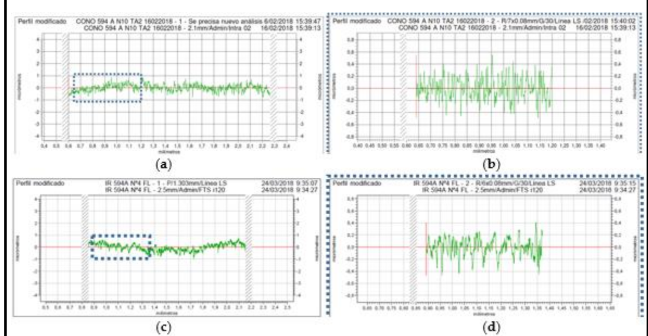
- **Adherence**
  - A Rockwell C indentation is performed with a load of 150 kg → trace edges are analyzed by optical microscope to evaluate adherence
  - VDI 3198 indentation test is used to set adherence grade



- **Friction Torque**
  - Two friction torque test protocols:

Test	Preload (kN)	Speed Range (rpm)	Temperature	Test Time (min)
Stribeck test	8	0–200 ramp	room	1,5 min
Torque to Rotate test	0–15 (1.5 kN/step)	30	room	10 min (1 min/load step)

  - Friction torque tests were carried out in collaboration with FERSA BEARINGS SA in an AX-180 TT test rig whose features are:
    - Tapered roller bearings assembled in tandem configuration.
    - Protective oil was applied as bearing lubrication
    - Test rig size: 450 mm × 1220 mm
    - No. of stations: 1
    - No. of bearings, 2
    - Bearing outer diameter size, up to 180 mm;
    - Axial load (max.), 15 kN;
    - Speed range, 0–1000 rpm
    - Torque (max.), 100 N m.

Inner Ring Raceway		Inner Ring Flange
Profile shape	**Roundness**	
→ Coating has perfectly copied the shape of raceway logarithmic profile	→ Values obtained: from 0.82 to 2.34 µm, which are under FERSA BEARINGS S.A. limit (RONt < 6 µm)	→ Coating has also perfectly copied flange profile shape
		

NOTE:

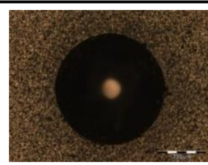
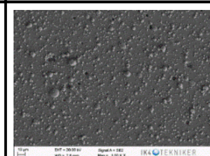
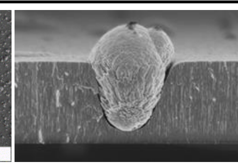
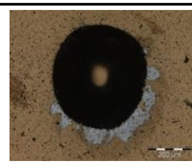
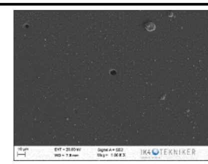
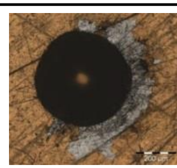
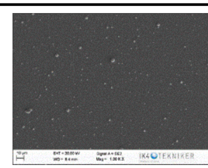
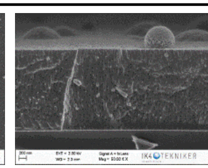
(a)-(b): uncoated bearing

(c)-(d): coated bearing

4.2. Results. PVD coating results

Coating Design	R_a (µm)	Thickness (µm)		Adherence (HF)	Hardness (HRC)	
		Adherence Layer	Total		Before PVD Application	After PVD Application
D1	0.540	1.24	3.67	HF1	60.7	59.0
D2	0.240	0.21	2.61	HF5	60.4	59.1
D3	0.080	0.46	2.86	HF5	60.5	59.7
D4	0.433	1.23	3.74	HF1	59.6	59.2

NOTE: Ra ≤ 0,15 µm; HFx ≤ HF4; HRC = 59 - 61

	Adherence results	Adherence layer drops
D1		 
D2		
D3		 
D4		

- Not possible to obtain a compromise between adhesion and low roughness → post-polish process is proposed to lower roughness
- **Samples D1 and D4**:
  - \+ acceptable adherence results
  - \- roughness → improvement
  - \+ highest thickness values
  - **→ post-polishing process**
- Samples D2 and D3 are discarded
  - \- low thickness → peeling off when applying post-polishing process

Coating Design	Post-Polish Configuration	R_a (μm)		Thickness (μm)		Adherence (HRc)
		Before Post-Polish	After Post-Polish	Before Post-Polish	After Post-Polish	
D1	A1	0.540	0.371	3.67	3.30	HF1
	A2	0.540	0.226	3.67	3.25	HF1
	B	0.540	0.171	3.67	2.45	HF1
D4	B	0.433	0.082	3.74	3.45	HF1

Post-polish method A (configuration A1 and A2)

– High Roughness (R_a > 0,15 μm)
– High thickness variation
→ Discard

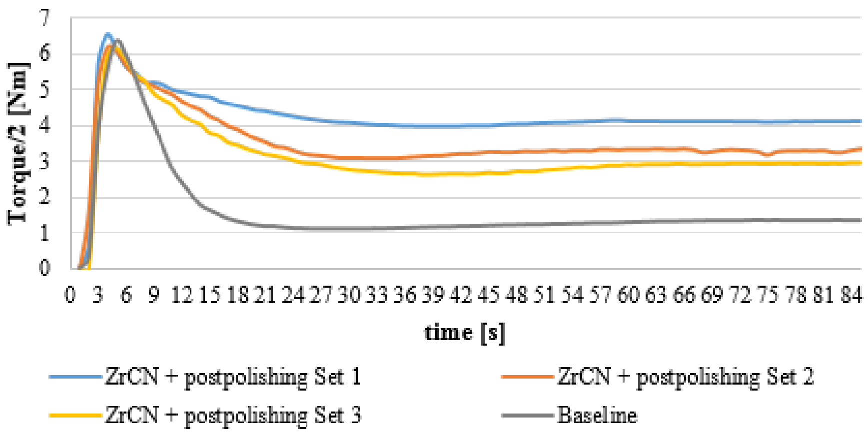
Post-polish method B

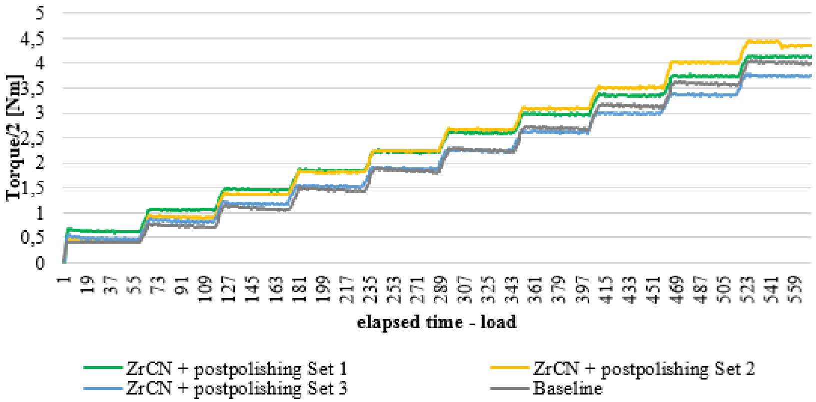
+ Roughness value ok (R_a < 0,15 μm)
+ Low thickness variation (only 7.75% reduced from blank sample)

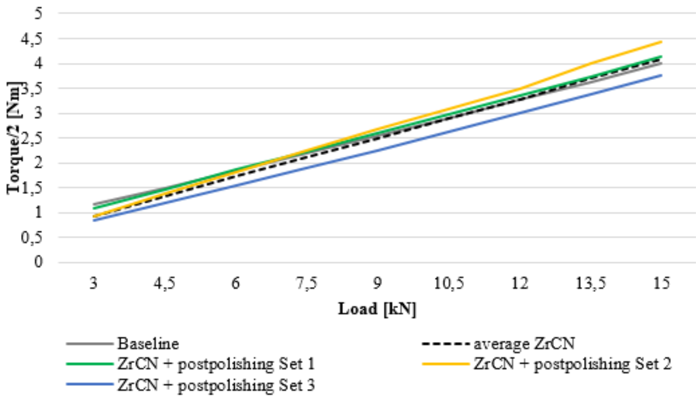
Bearing samples:

D4 coating + post-polish B

Stribeck test	Torque-To-Rotate
• Coated bearing friction > uncoated bearing friction → no improvement in tribological behavior at low load conditions	• Friction behavior is similar for all the bearing samples at low speed and loads • Set 3 achieves torque values lower than baseline torque at high loads







5. Conclusions

- A strategy based on **PVD coating of rolling bearings** is proposed in order to improve friction during bearing performance
- Different PVD coating designs have been tested varying composition and deposition time.
- Coatings with a **longer deposition time** obtain good adherence results although roughness allowed value of 0.15 is not achieved.
- Only samples coated with an **interlayer of TiN** instead of TiZr obtain acceptable roughness values at the expense of a bad adherence.
- A **post-polishing process** is proposed for the samples with good adherence in order to reduce roughness.
- Post-polishing method based on walnut shell additivated with a silica base abrasive 80% achieves proper roughness values of 0.082 on samples with a ZrN bilayer.
- These samples are subjected to friction torque test to evaluate their tribological behavior. **Hardly any improvement is observed in the friction torque** for the coated samples, neither at low load, nor at low speed

THANK YOU VERY MUCH FOR YOUR ATTENTION