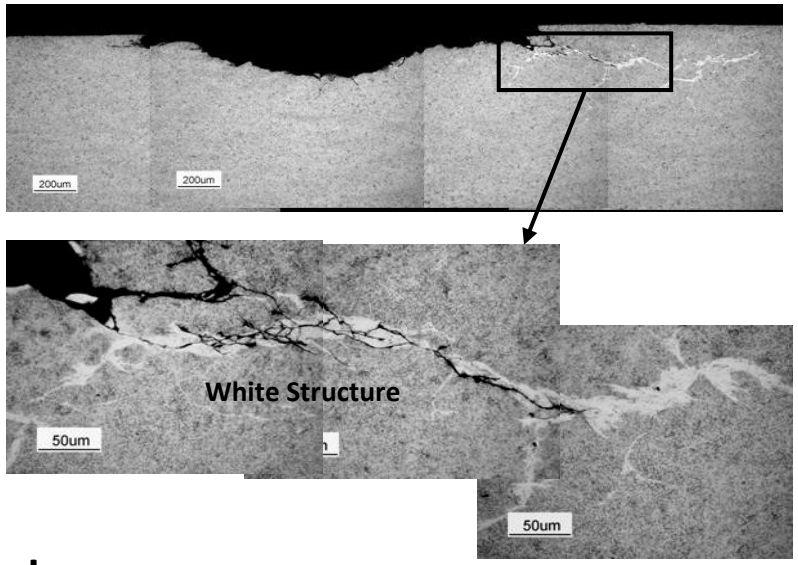
Combating WEC Throughout The Drivetrain

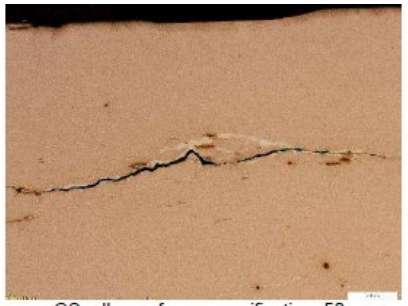
2/21/23

› Paul Brda – Strategic Segment Manager

Observed White Etch Area and Crack Examples

- Main Shaft
- HS-IS with Black Oxide
- HSS with Through Hard outer and Case Carb Inner




GS roller surface, magnification: 50x


White structure and cracking, magnification: 100x


White structure, magnification: 500x


Roller Core, magnification: 500x

TH Main Shaft Outer Ring with DLC Rollers

- The fracture origin on the outer ring (OR) was beneath the spalled raceway. Pitting corrosion was found on the Inner ring (IR) and OR and confirmed by SEM/EDS analysis.

- White structure was found below cracks and corrosion pitting found on the outer ring.

OR raceway surface cracks and peeling

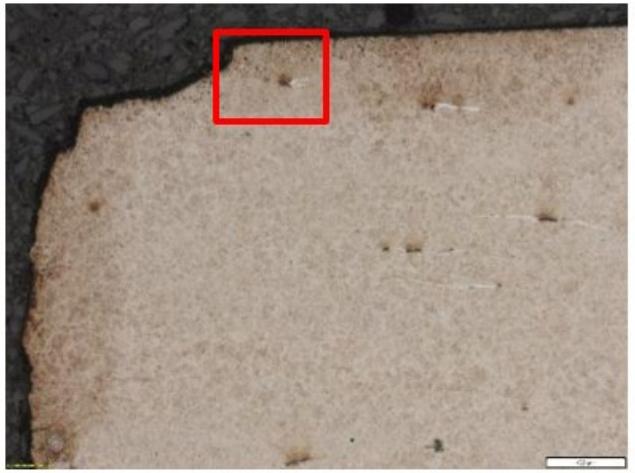
White structure on the raceway surface, Magnification: 500x

White structure below the raceway surface, Magnification: 500x

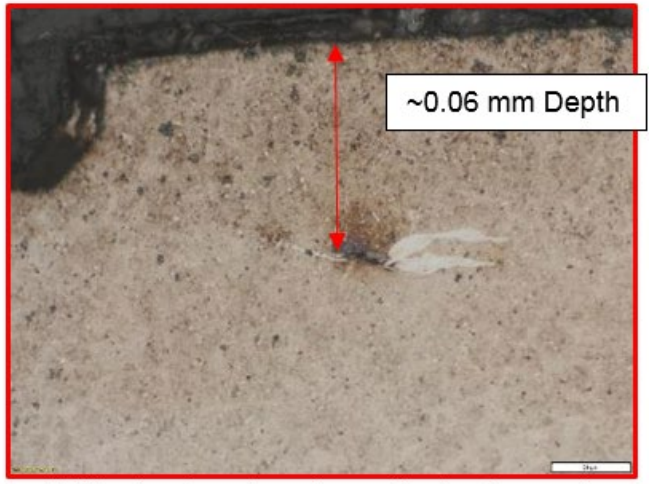
White structure below the raceway surface, Magnification: 500x

TH HSIS CRB Inner Ring with Black Oxide

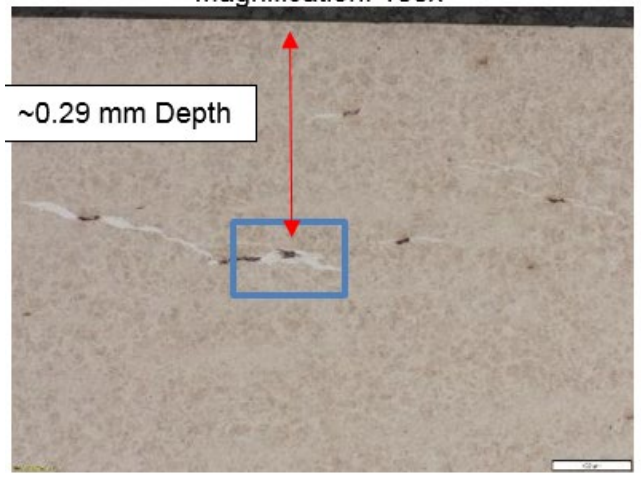
- Both samples exhibited detrimental white structure near the fracture surface.
- The white structure found is likely the result of a breakdown in the lubrication and hydrogen embrittlement, resulting in the creation of brittle white structure where cracks originated.
- New non-tempered martensite was found on sample #1 at the fracture surface and is most likely due to the high load and rubbing between the fracture surfaces after hydrogen embrittlement had occurred.
- Both samples appear to be through-hardened steel with a 1 µm layer of black oxide coating.



Circumferential cut of the fracture surface, Magnification: 100x



White structure found near the fracture and raceway surface, Magnification: 500x

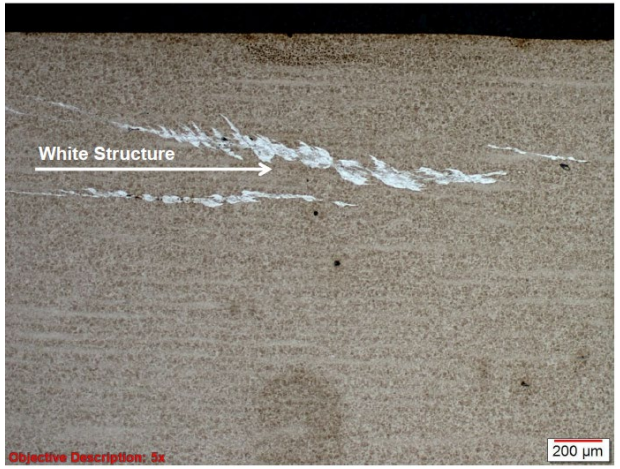


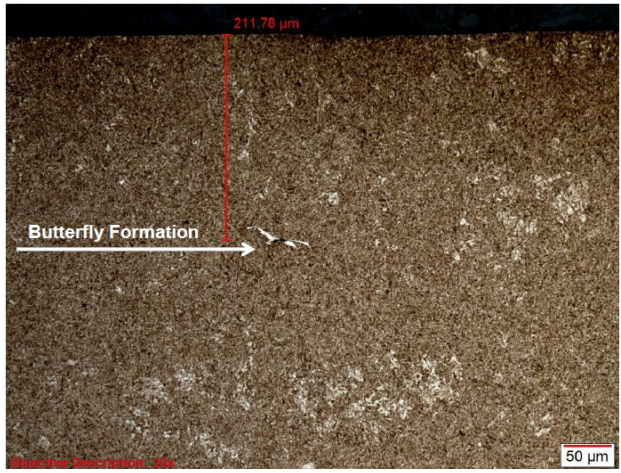
Additional white structure, Magnification: 100x

Magnification: 500x

HSS TRBs with TH outer and CC Inner

- Both outer rings exhibited a through hardened microstructure (difficult to discern visually whether bainite or martensite).
- Both inner rings exhibited a carburized case and core microstructure.
- White structure was observed in both outer rings
- Outer ring 30328 exhibited a thin layer of new martensite on the raceway surface. This would be consistent with frictional rubbing due to skidding of the rollers on the surface.
- Early butterfly formation was observed in inner ring 30328 at ~200µm beneath the raceway surface.
- No observations of white structure were made in inner ring 31328.





Lab Created White Etch Area and Crack Testing

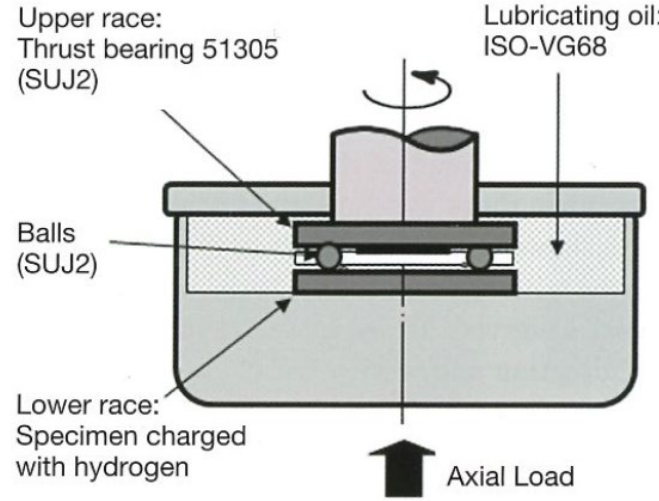


Fig. 4 Schematic of the thrust type rolling contact fatigue test machine.

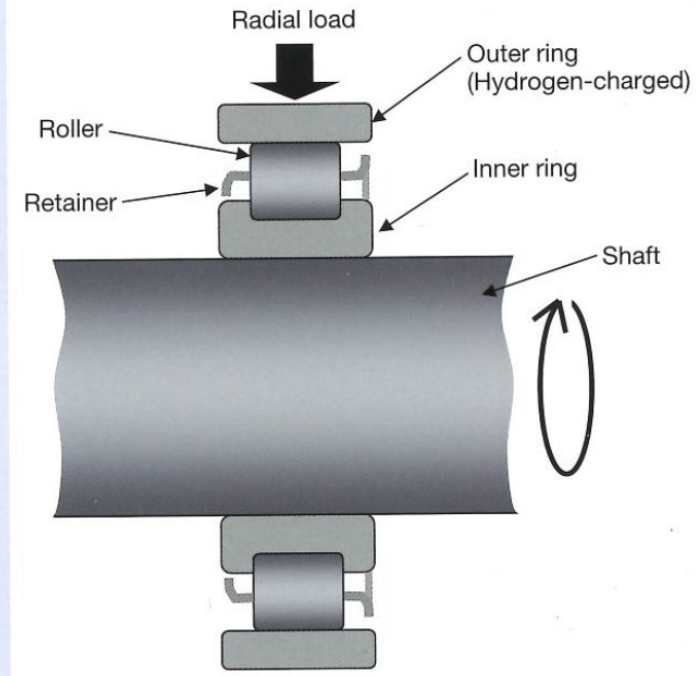
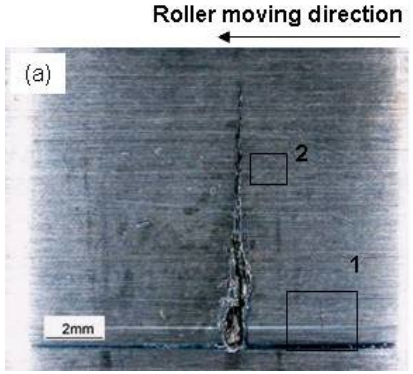
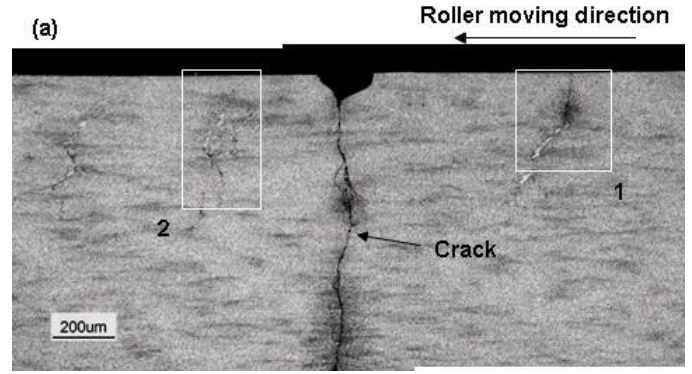


Fig. 7 A schematic of radial type bearing test machine.



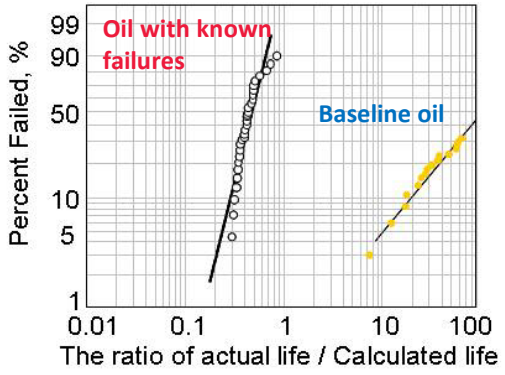


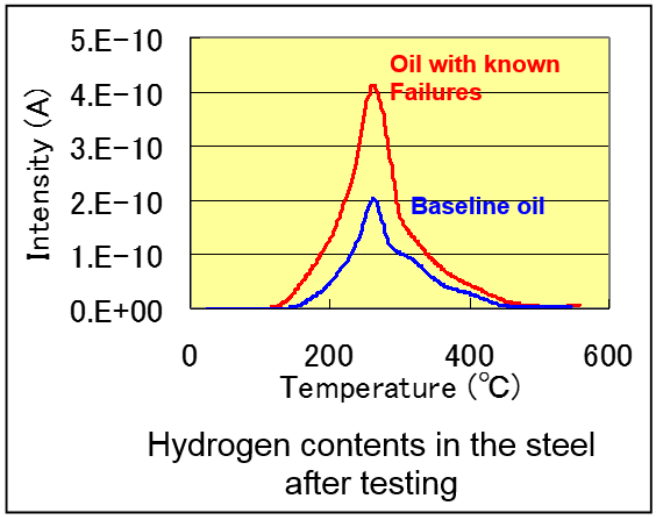
Recreating Hydrogen Generation - Lubricant

To test, baseline oil and oil with known cases of WEC were chosen allowing us to compare the life results of a bearing using the baseline lubricating oil and the oil with known failures.

While analyzing this failure we found higher concentrations of hydrogen in the bearing steel where white structures form

We monitor the hydrogen level because of a supposed embrittlement concern hence the reason this is discoverable

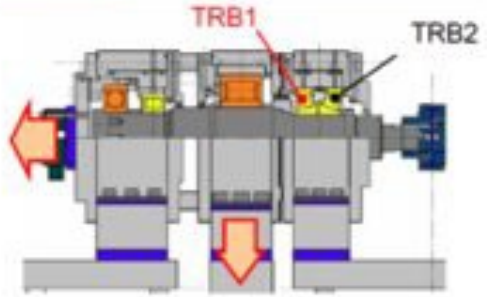




Hydrogen contents in the steel after testing

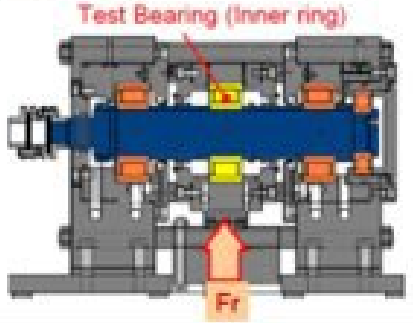
➢Testing condition

	TRB1
bearing size	Φ130 mm × ϕ280 mm × 63.75 mm
bearing load	Fr:240 kN, Fa:75 kN
P/C	0.37
Rev. speed	800 rpm
lubricant	Castrol Optigear Synthetic A 320
lubricator	Oil bath
Testing time	576 hrs (= L_{10})



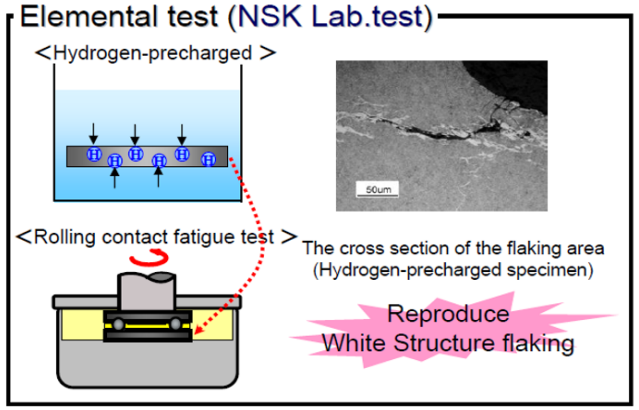
➢Testing condition

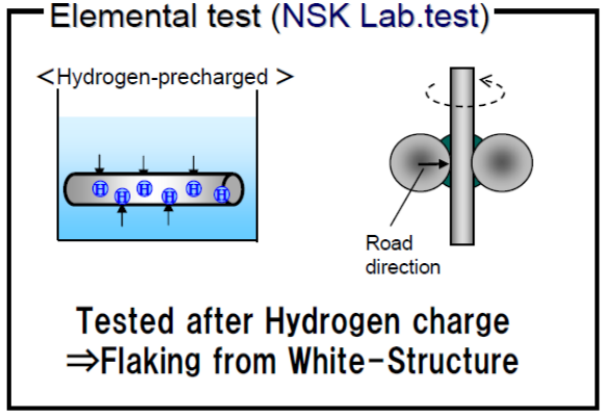
	CRB
bearing size	Φ130 mm × ϕ280 mm × 93 mm
bearing load	Fr: 196 kN, Fa: 0 N
P/C	0.23
Rev. speed	1300 rpm
lubricant	FBK OIL RO 68
lubricator	Forced lubrication
Testing time	1363 hrs (= 3 × L_{10})

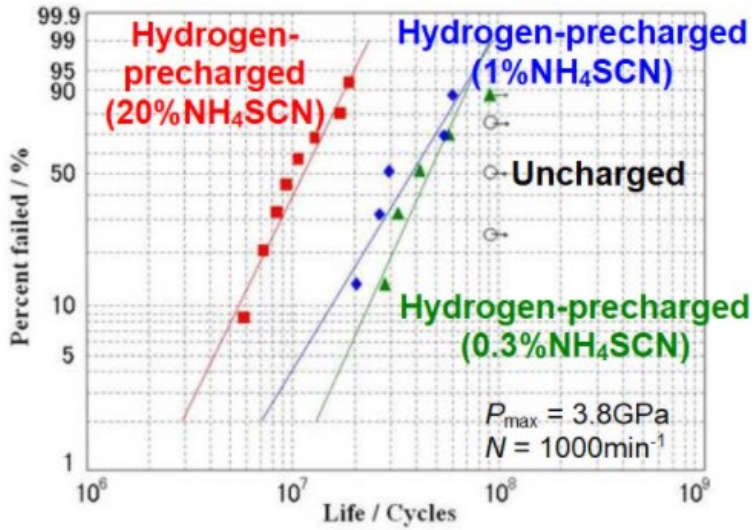


Recreating White Structure

- Testing led to the hypothesis that hydrogen generates from decomposition of the lubricant and absorbs into the test bearings increasing the hydrogen level in the material
- Next was to verify the hydrogen effect using a controlled method
  - Diffusion of hydrogen into steel using Ammonium Thiocyanate - NH_4SCN
- Rolling contact fatigue life became shorter in the hydrogen-charged specimens, and the life was dependent on the amount of hydrogen content, as well as White Structure is observable in the hydrogen-charged specimens







Results of rolling contact fatigue life tests of hydrogen-precharged specimen
(Uyama et al., Tribology Online, Vol.6, 2011)

Hydrogen Generation Explanation

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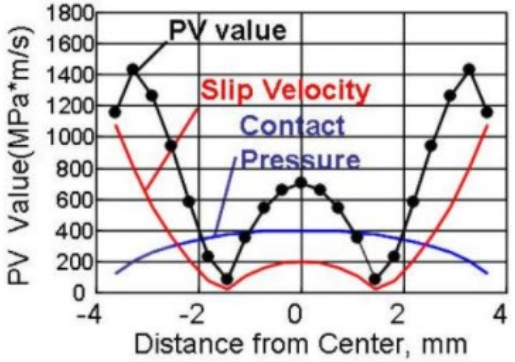
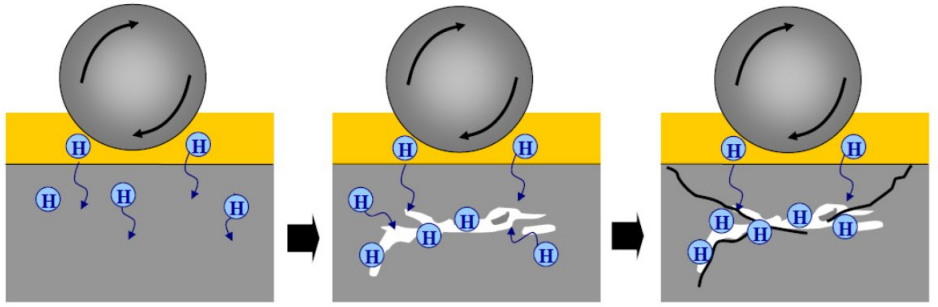
White Structure flaking

- Hydrogen generation
  - Type of lubricant
    - Base oil
    - Additives
  - Slip (Metal Contact)
    - Differential slip
    - Spin slip
    - Vibration
    - Variable load
    - Variable rotating speed
    - Poor lubrication film
  - Static electricity
    - Friction between rubber and metal
    - External field condition (motor/generator/ inverter leakage)
- Resistance to hydrogen
  - Materials
    - Alloy elements
    - Heat treatment

White structure flaking occurs at the largest slip area on the raceway.





Hydrogen generation and diffusion

White Structure formation (Localized microstructural changes)

Cracking and flaking

Solution Material for White Etch Area and Cracking

- Material
- Heat Treatment
- Results

The Factors Influencing White Structure Flaking

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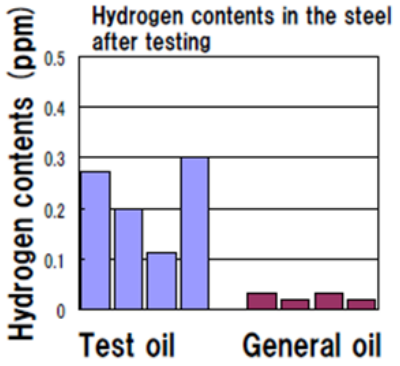
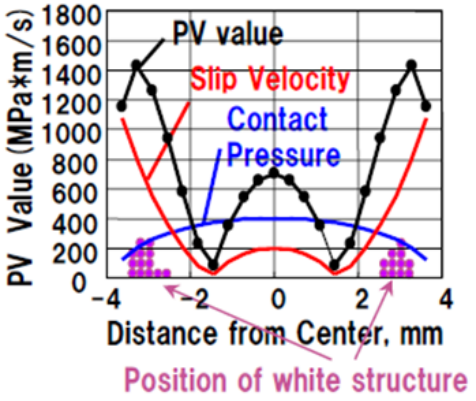
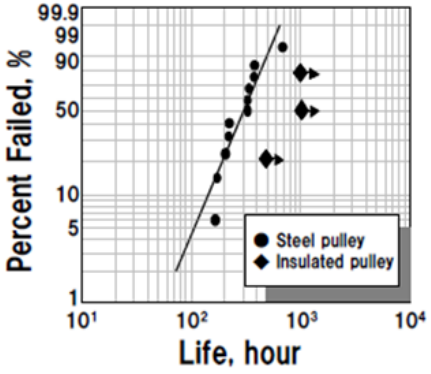
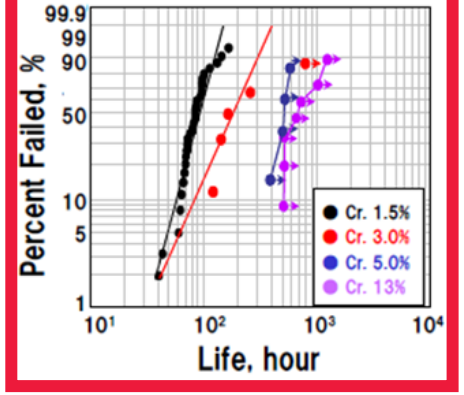
White Structure flaking

- Hydrogen generation
  - Type of lubricant
  - Slip (Metal contact)
  - Electricity
- Resistance to hydrogen
  - Materials



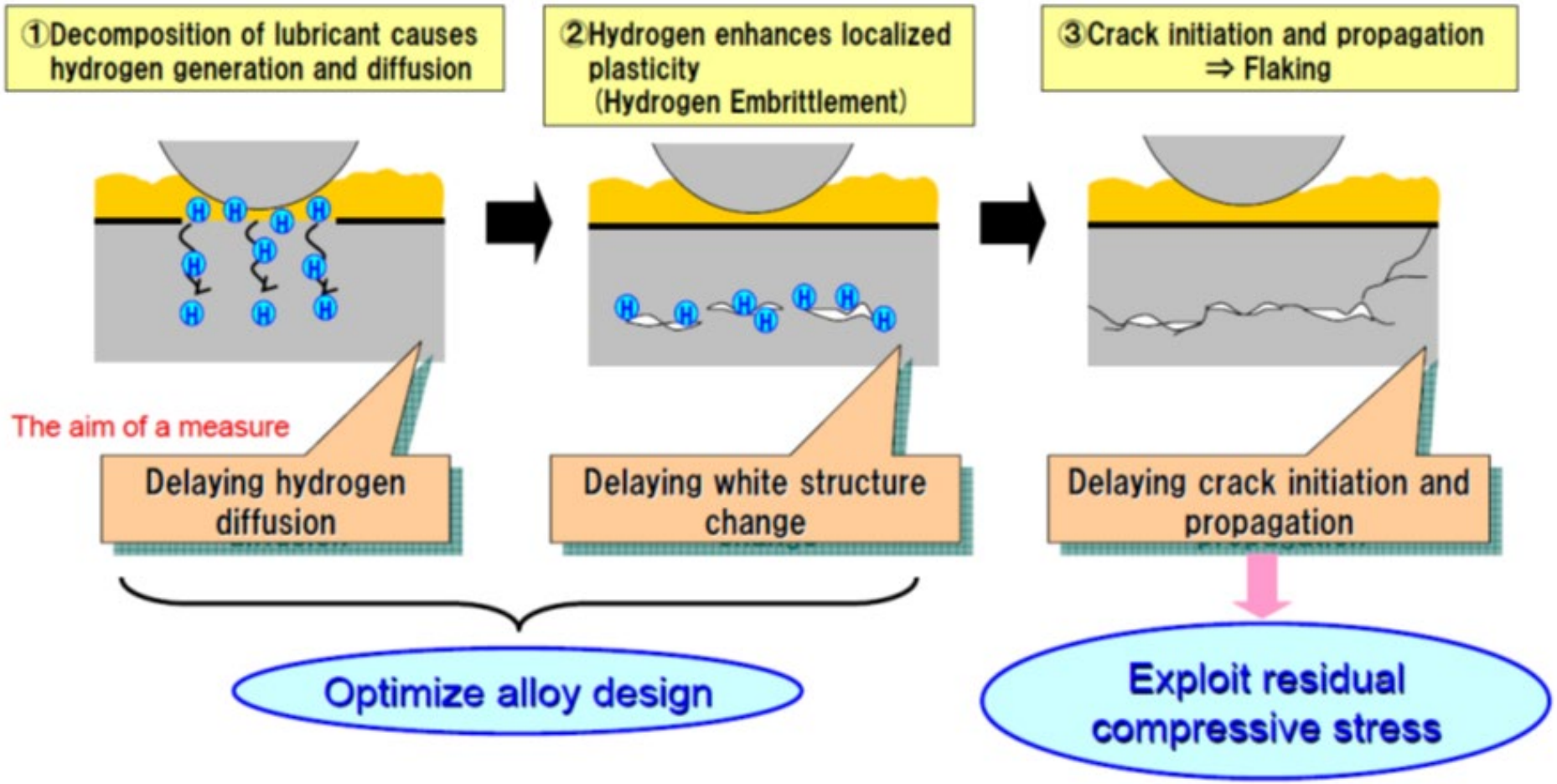






Changing material has a large impact on life performance from main shaft through the gearbox

Solution - Bearing Material and Heat Treat



Solution - Bearings Material and Heat Treat

Low to Medium carbon base steel with optimized alloy content and carbonitrided heat treatment to resist hydrogen diffusion and crack propagation

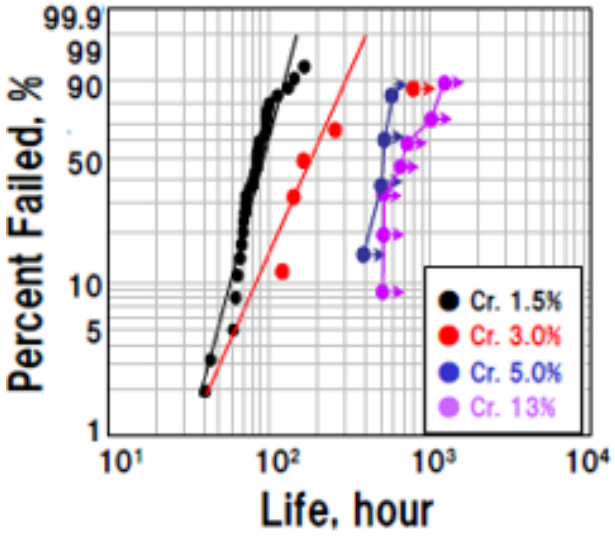
Rolling contact fatigue life becomes longer with an optimization in various alloying elements

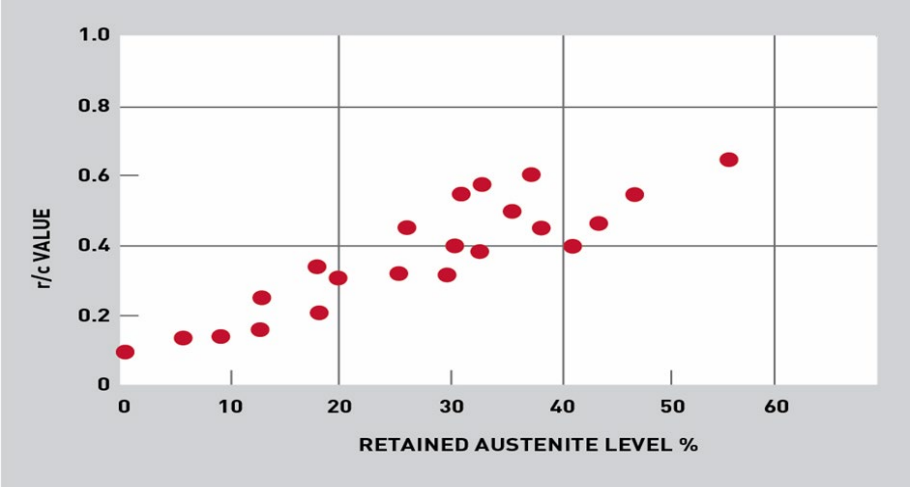
- Chromium content
- Nickel content
- Others

The material's carbonitriding process creates a compressive stress at the surface of the part hindering crack propagation

- Increased amount of retained austenite for surface-initiated damage

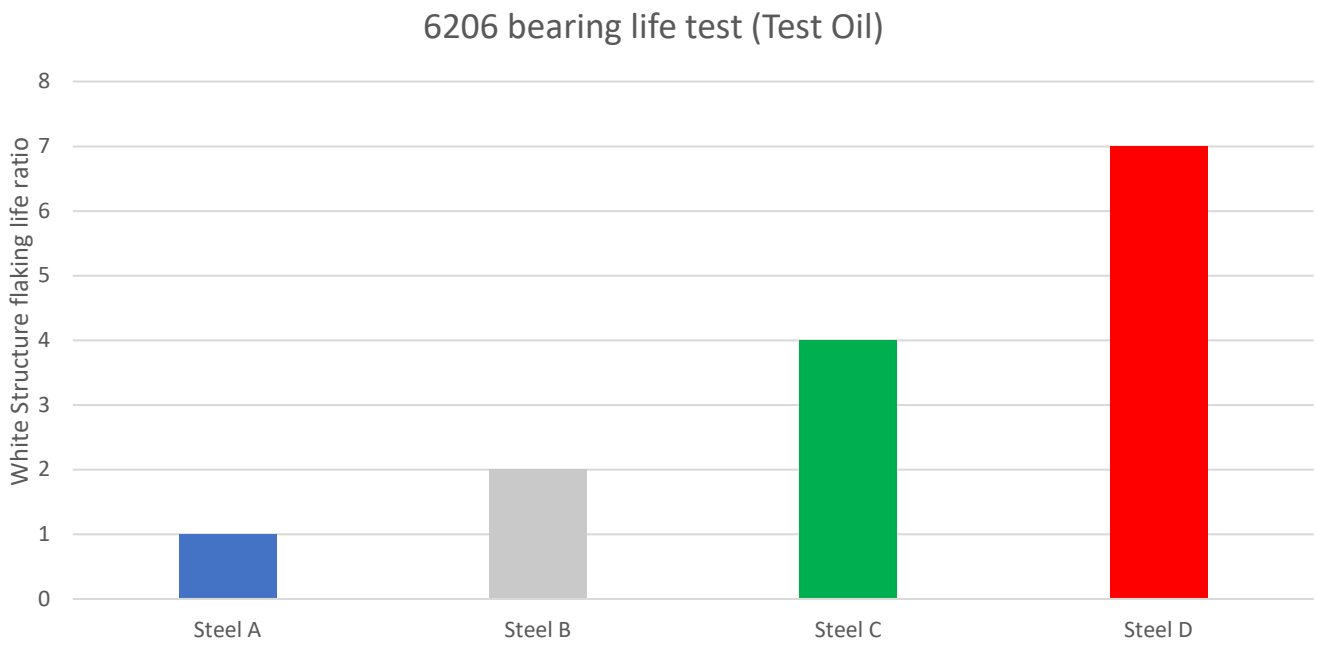
Being the material is impregnated with a high amount of carbon at its surface and into a depth typically well below where the initial white structures tend to form, this extends the length of time and also makes it more difficult for the White Structure to occur let alone reach the flaking failure.





Results of Materials and Heat Treat Testing

- Carburized material can offer 2x life over through hard
- Carbonitrided material can offer 4x over through hard and 2x vs case carburized
- Varying the alloys in the steel can offer further resistance to WEC (steel C and D)



	Steel A	Steel B	Steel C	Steel D
Material	Conventional steel SUJ2	Carburized steel	**Carbonitrided steel**	**Carbonitrided steel**
Alloy design			effective	optimal
Heat treatment	Through hardened	case hardening	Case hardening with nitriding	Case hardening with nitriding

Conclusions

- WEC has been observed in multiple applications and positions of the drivetrain
- Black oxide coating can help, but does not always solve WEC issue
- Case carburized can help to extend life due to compressive stresses in the material
- Carbonitriding can offer advantages and improvements further over case carburized due to alloys in the material and different heat treatment

THANK YOU

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