

Mitigating Oxidation of Lubricating Greases Used in Heavy Equipment

Dr Gareth Fish PhD DIC CLS CLGS

Senior Technical Fellow

Lubrizol

Wickliffe Ohio USA



Imagined for Life. Enabled by Science.™

Today's Presentation

- Introduction
- Bearing test methods
- Laboratory oxidation and degradation test methods
- Greases to be evaluated
- Test results
- Summary
- Conclusions
- Acknowledgements

Introduction

- The improvement of grease life is an important issue for industrial and automotive bearings
 - Improved life leads to longer re-greasing intervals
 - Reduced grease consumption
 - Reduced environmental impact
- Understanding the lubrication needs of bearings makes it possible to formulate improved greases
 - Evaluation of used grease for degradation modes
- The use and understanding of screening methods aids in the development of improved greases
 - Including environmental impact assessments
- The grease performance must be verified in standard bearing tests

What Impacts Performance?

- The base grease contribution:
 - Base oil viscosity
 - Base oil type
 - Consistency
 - Shear stability
 - Homogeneity
 - Apparent viscosity at operating temperature
 - Thickener structure and content
 - Oil bleed stability at ambient temperatures
 - Oil bleed at elevated temperature

For detailed explanation see Fish, G. and Ward Jr, W.C. "Development of Greases with Extended Grease and Bearing Life" 2009 ELGI 21st Annual Meeting, Gothenburg, Sweden. Published in ELGI Eurogrease

What Impacts Performance?

- The additive package contribution:
 - Anti-oxidant
 - Anti-wear
 - Extreme pressure (in an EP situation)
 - Corrosion inhibitor
 - Friction modifiers
 - Tackifiers
 - Oil bleed suppressants
 - Unsaturation of any hydrocarbon chains present

For detailed explanation see Fish, G. and Ward Jr, W.C. "Development of Greases with Extended Grease and Bearing Life" 2009 ELGI 21st Annual Meeting, Gothenburg, Sweden. Published in ELGI Eurogrease

How Is Life Increased?

- In high temperature oxidation tests
 - Increasing oxidation resistance / reducing degradation
 - Reducing wear
 - Reducing excessive oil bleed
 - Prevention of lacquering
- In wear tests
 - Reducing wear
 - Increasing surface protection
 - Increasing oxidation resistance / reducing degradation
 - Increasing film thickness

For detailed explanation see Fish, G., Ward Jr, W.C. and Capitosti, S.M., "Grease Additives for High Temperature Bearing Applications" 2014 ELGI 26th Annual Meeting, Dubrovnik, Croatia. Published in ELGI Eurogrease

How is Grease Life Increased?

Failure mode	Solution
Grease degradation	Increase oxidation resistance
	Use a higher temperature thickener
Raceway lacquering	Use a higher quality base oil
	Increase oxidation resistance
Raceway rust and corrosion	Increase levels of rust and corrosion inhibitors
	Incorporate water resistant polymer
Excessive oil bleed	Incorporate a bleed reducing polymer or additive
Bearing wear	Optimize base oil viscosity
	Increase level of anti-wear / extreme pressure (EP) additives

For detailed explanation see Fish, G., Ward Jr, W.C. and Capitosti, S.M., "Grease Additives for High Temperature Bearing Applications" 2014 ELGI 26th Annual Meeting, Dubrovnik, Croatia. Published in ELGI Eurogrease

Bearing Test Methods

- All are designed to test the various important aspects of bearings
- Five types of test methods
 - Grease oxidation tests
 - Wear resistance tests
 - Grease shearing tests
 - Grease noise tests
 - Rolling contact fatigue tests

Grease Oxidation Test Methods

Test	Standard	Year	Bearing	Temperature (°C)
Wheel Bearing Grease Life at High Temperature	ASTM D3527	1976	Two tapered roller bearings 19.05 mm & 31.75 mm*	160
Grease Life at High Temperature (Pope Test)	ASTM D3336	1975	6204 C-3 DGBB	149 and 177 Elevated to 371
FAG FE 9	DIN 51821-2	1988	AC7206	120, 140, 160, 180, and 200
SKF ROF / ROF+	SKF methods		6204 C-3 DGBB	120, 140, 160, 180, and 200

*inner diameters

Standard Conditions

FAG FE 9

- FE 9 is a high temperature bearing grease oxidation test
 - It is also used to define the upper operating temperature of a bearing grease under ISO 6743-9 and ISO 12924 ($F_{50} > 100$ hours)
- FE 9 runs 62 mm AC ball bearing
 - Axial loads: 1500, 3000, 4500 Newtons
 - Speed: 6000 r/min and 3000 r/min ($KV40 > 300 \text{ mm}^2/\text{s}$)
 - Temperatures: 120 °C, 140 °C, 160 °C, 180 °C, 200 °C
 - 5 bearings are run to failure
 - F_{10} and F_{50} determined
- Standard DIN 51821-2 conditions are temperature plus
 - Axial Load = 1500 N and 6000 r/min



Wear Resistance Test Methods

Test	Standard	Year	Bearing	Temperature (°C)
Rolling Bearing Grease performance test	IP168	Prior to 1965	6308-C3	Ambient to 177
FAG FE 8	DIN 51819-2	1988	AC 7312B (polyamide or metal cage) TRB 31312	Ambient, 120, 140, 160, 180, 200
SKF R2F	DIN 51806 (obsolete)	1988	22312 Double row spherical roller	60 to 160

FAG FE 8 – Test Bearings And Conditions

Bearing Type : Cage : Temperature Limit (°C)			Test Conditions	
Type A AC : Polyamide : 120	Type B AC : metal : 200	Type C TRB : metal : 200	Speed (r/min)	Loading (kN)
X	X		7.5	80
Y	Y	Y	75	80
		X	75	50
		Y	750	20
		Y	1,500	10
Y	Y	X	3,000	10
Y	Y		6,000	5

X = recommended conditions, Y = alternate conditions

Heavy Duty Equipment Greases – Base Fluids

- Slower moving heavy duty greases typically require base oil viscosities of ISO VG 460 or ISO VG 680
- Standard Group I and Group II paraffinic base oils have maximum kinematic viscosities of around 120 mm²/s at 40 °C
 - A 750 naphthenic oil has a kinematic viscosity of around 145 mm²/s at 40 °C (KV40)
 - These fluids cannot achieve the required viscosity grades
- A few options are available to grease formulators to boost the base oil viscosity
 - 2500 Brightstock (BS 150) with a kinematic viscosity of around 500 mm²/s at 40 °C
 - Liquid polyisobutylene (PIB) polymers with KV40 between 8,000 and 200,000
 - Solid polymer such as an olefin co-polymer (OCP)
 - Higher viscosity liquid polymer (UPP) as outlined by Clark et al
 - Higher viscosity polyalphaolefins with KV40 between 400 and 1500 mm²/s

Heavy Duty Equipment Greases – Additives

- Slower moving heavy duty greases typically require significant additive treat rates
 - Load carrying boosters such as extreme pressure (EP) additives
 - Anti-oxidants to reduce the degradation of the grease
 - Anti-wear additives to reduce wear of hardened steel mating surfaces
 - Rust inhibitors to prevent the ferrous corrosion of bearing surfaces
 - Metal deactivators to reduce the impact of the EP additives on yellow metals
 - In applications where there is reversing motion, solid lubricants such as molybdenum disulfide, graphite and or calcite are often applied
- Typical specifications include requirements to pass the following tests
 - 4-Ball EP and Wear
 - Rust and corrosion
 - Oxidation

Grease Issues

- Previously published work showed that there were two primary influences on lithium complex grease life
 - Base fluid composition
 - Anti-oxidant (AO) additives
- When brightstock was used as the viscosity booster
 - When brightstock degrades, it forms viscous gummy degradation products
 - The grease has shorter life in FE9 Tests and fails through increased torque
 - Higher levels of AO additives can mitigate this but no completely solve the issue



For detailed explanation see Fish, G. and Ward Jr, W.C. "Development of Greases with Extended Grease and Bearing Life" 2009 ELGI 21st Annual Meeting, Gothenburg, Sweden. Published in ELGI Eurogrease

Comparison Lithium Complex Greases

Grease	Test Method	A	B
Thickener	Formulation	2:1 azelaic lithium complex	2:1 azelaic lithium complex
Soap (wt%)	Calculation	8.62	8.62
Base oil viscosity booster	Formulation	2500 Brightstock (KV40 = 500 mm ² /s)	Polyisobutylene (KV100 = 2000 mm ² /s)
Base oil kinematic viscosity KV40 (mm ² /s)	ASTM D445	167.0	168.0
KV100 (mm ² /s)	ASTM D445	16.0	17.3
Viscosity index	ASTM D2270	96	111
Dropping point, °C	ASTM D2265	299	261
Oxidation induction time (OIT) at 180 °C, minutes	PDSC ASTM D5483	68.9	104.9
Wheel bearing grease life (hours)	ASTM D3527 (average of 3 tests)	33	133

PDSC = Pressure differential Scanning Calorimetry

High Temperature Grease Life Testing Data

Test Temperature (°C)	Viscosity Booster	Weibull Probability life (hours)		Pass / Fail
		F ₁₀	F ₅₀	
140	2500 Brightstock (KV40 = 500 mm ² /s)	221	288	Pass
	Polyisobutylene (KV100 = 2000 mm ² /s)	280	349	Pass
160	2500 Brightstock (KV40 = 500 mm ² /s)	42	57	Fail
	Polyisobutylene (KV100 = 2000 mm ² /s)	87	146	Pass

At 160 °C the grease with the PIB was significantly better than the grease with brightstock

FE 8 Testing – TRB High Speed - Low Load

DIN 51819 Tapered Roller Bearings 10 kN 3000 r/min 500 hours 120 °C								
Grease B	Rolling Elements				Cage			
	Test Run	Weight loss (mg)	Weibull Predicted Loss (mg)		Test Run	Weight loss (mg)	Weibull Predicted Loss (mg)	
	1	5	W ₅₀	8.8	1	17	W ₅₀	11.1
	2	13	Target	≤ 35	2	6	Target	100



Bearing 1

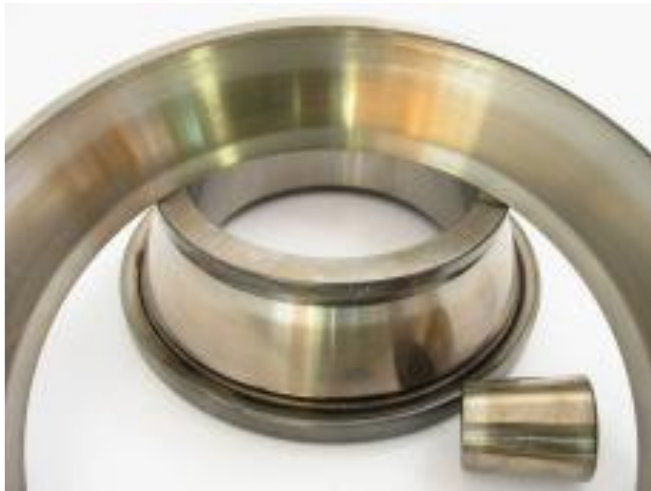


Bearing 2

No evidence of raceway, cage or rolling element lacquer

FE 8 Testing – TRB Low Speed - High Load

DIN 51819 Tapered Roller Bearings 80 kN 75 r/min 500 hours Monitor temperature								
Grease B	Rolling Elements				Cage			
	Test Run	Weight loss (mg)	Weibull Predicted Loss (mg)		Test Run	Weight loss (mg)	Weibull Predicted Loss (mg)	
	1	1	W ₅₀	4.6	1	26	W ₅₀	31.0
	2	13	Target	≤ 35	2	35	Target	≤100



Bearing 1



Bearing 2

No evidence of raceway, cage or rolling element lacquer

Thickener Effects on Grease Life

- According to the NLGI Grease Guide*, urea (diurea and polyurea) thickened greases have significantly better oxidation stability than soap thickened lubricating greases
 - The metal base of the soap has been shown to promote oxidative degradation of the base fluid
 - Anti-oxidants have been shown to mitigate this degradation, but this adds to formulation costs
 - An ashless performance package was incorporated into two different base greases, one with a diurea thickener and the other with a diacid lithium complex
 - The base fluid was the same 600N Group I paraffinic mineral oil (KV40 = 112 mm²/s)
 - Standard NLGI GC-LB tests were carried out on both greases

Thickener Effects on Grease Life

Property	Test Method	NLGI GC-LB requirement	Grease C	Grease D
Thickener			Urea	LiX
Worked penetration	ASTM D217		281	276
Dropping point (°C)	ASTM D2265	≥ 220	265	255
Bearing rust rating	ASTM D1743	pass	pass	pass
4-ball wear scar (mm)	ASTM D2265	≤ 0.60	0.44	0.55
4-ball EP Weld point LWI	ASTMD2266	≥ 200 ≥ 30.0	200 37.8	315 46.8
Fretting wear weight loss (mg)	ASTM D4170	≤ 10	<1.0	7.2
Wheel bearing grease life (hours)	ASTM D3527	≥ 80	200	120
Water washout (wt%)	ASTM D1264	≤ 15.0	1.3	5.3
Oil separation (wt%)	ASTM D1742	≤ 6.0	0.8	1.8

Base Oil, Additives, and Thickener Effects

- A major use of high temperature ashless urea greases is to lubricate electric motor bearings
 - A new additive package with higher levels of anti-oxidants grease was developed
 - A polyurea thickened group I oil (Grease E) the wheel bearing life was 180 hours
 - A diurea thickened group II oil (Grease F) the wheel bearing life was 300 hours
- In many electric motor bearing greases life is determined by the ASTM D3336 Grease Life (Pope) Test running under low load at 10,000 r/min
 - Target is an $F_{50} > 500$ hours at 177 °C
 - To meet this extended life at elevated temperature, very high levels of AO are needed

For detailed explanation see Fish, G., Ward Jr, W.C. and Capitosti, S.M., "Grease Additives for High Temperature Bearing Applications" 2014 ELGI 26th Annual Meeting, Dubrovnik, Croatia. Published in ELGI Eurogrease

Base Oil, Additives, and Thickener Effects

Property/ Grease	Test Method	C	E	F
Base oil API group /		I	I	II
Thickener		Diurea	Polyurea	Diurea
Ashless Additive package descriptor		Standard	AO enhanced	AO enhanced
High temperature oil bleed 30 hours at 100 °C (%wt)	ASTM D6184	3.2	4.6	2.7
4-ball wear scar diameter (mm)	ASTM D2266	0.44	0.61	0.44
PDSC OIT at 210 °C (minutes)	ASTM D5483	41.5	53.5	57.0
Wheel bearing grease life (hours)	ASTM D3527	200	180	300
Pope High Temperature Grease Life F ₅₀ (hours) 10,000 r/min, 177 °C,	ASTM D3336	425	323	620

Summary

- It has been demonstrated that by proper selection of the base oil, grease and additives can be developed with improved life
- Polyisobutylene viscosity boosters can reduce the impact of grease degradation on performance
- Urea grease thickeners offer significantly enhanced life over lithium complex greases
 - The type of urea thickener and base fluid group also impacts life
- Higher levels of anti-oxidant levels also significantly improve grease life

Imagined for Life. Enabled by Science.™