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Impact of Rheology on Tribological Properties

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Abstract

Compared to oils, greases have a number of advantages with respect to the construction and service of lubricated components. However, due to the visco-elastic behavior of greases there are certain constraints to consider regarding the flow and tribological properties. Therefore, having an instrument and methods to investigate the visco-elastic and frictional behavior of greases over an extended temperature range is highly desirable. A rotary tribometer as well as a rheometer requires speed and normal force control, and torque measurement to acquire tribological data. An air bearing supported rotational rheometer allows the measurement in the whole range necessary for advanced rheological measurements. Oscillatory amplitude sweeps are very well suited to investigate the visco-elastic behavior and consistency of lubricating greases. Valuable information pertaining to the visco-elastic behavior, i.e. the storage and the loss moduli, as well as the stress values at the flow point, i.e. the yield stress, is obtained. Further, rheometers allow for tribological measurements of lubricating greases by employing a ball-on-three-plates measuring accessory. Measurements, such as Stribeck-curves, over a broad range of speeds especially down to very low speeds with high accuracy are possible.

The impact of complex rheological properties on the tribological properties of grease lubricated tribo-contacts is discussed for aspects of film formation, but also the impact of static and boundary friction.

Introduction

Viscometers are used to measure the viscosity of fluids with a simple relation between force and deformation rate. Viscosity of Newtonian fluids is constant, independent of the applied shear or deformation rate. Complex fluids in general are non-Newtonian and visco- elastic. For the characterization of such fluids a sophisticated rotational rheometer is required. In order to cope with the diversity of rheological testing, different applications like polymers melts, food, cosmetics, building materials, coatings, adhesives, to name a few, modern rotational rheometer offers a large flexibility with respect to environmental conditions and the ranges of the applied or measured properties like torque, deflection angle, rotational speed, or normal force.

In shear rheology the sample is confined in well-defined geometries like cone-and-plate, parallel-plate, or concentric cylinders with fixed gaps. This allows for the calculation of respective rheological properties from stress – strain relations relevant for the measuring geometry used [1].

In tribology, on the other hand, are the measuring geometries form an integral part of the investigated tribo-system. Two measuring bodies are pressed together by a normal load, and the coefficient of friction (COF) in relation to relative sliding speed is determined.

In shear rheology the surface of the fixtures do not have any influence on the rheological data as long as the conditions of laminar flow are met. In some cases the surfaces are treated or roughened in order to prevent slip and to assure a laminar flow field. Therefore rheology uses the test fixtures to apply deformation onto the sample, whereas they are part of the test specimen in tribological tests.

However in tribological tests, forces, movements and normal loads need to be applied or measured, as in the case of rheology. Modern rotational rheometers are equipped with excellent speed and torque control as well as accurate normal force detection and a precise control of the temperature over a wide range. All these features can also be used for tribology
as well, which led to the idea to design an accessory enabling tribological measurements on a conventional rotational rheometer.

The aim of this paper is to give an overview of the impact of greases on the tribological properties. The impact is discussed using Stribeck curves and the impact of rheological properties of greases on them.

Background on greases

Greases find their use in numerous applications. Compared to oils, they have a number of advantages with respect to the construction and service of lubricated components. However, due to the visco-elastic behavior of greases, there are certain constraints to consider. For example, when greases are used in automotive application, they should show good performance characteristics over a large temperature range. Car manufacturer for example demand that greases used in cars should perform at temperatures as low as -40°C. Therefore having an instrument and methods to investigate the visco-elastic and the tribological behavior of greases over an extended temperature range is highly desirable. Of special importance from the rheological side are the yield and the flow behavior, i.e. the apparent yield and flow points of the greases. They determine the stresses at which the greases are yielding or flowing, respectively [3]. One method to measure theses stresses, which will be integrated in the DIN standard [4] is a so-called oscillatory strain sweep. In such a measurement, oscillatory movements with increasing amplitude of the strain are applied to the sample and the resulting oscillatory stress response is measured. Oscillatory measurements have the advantage that it is possible not only to measure viscous behavior at a constant rotational movement, but also gain information on viscous and elastic, and thus, visco-elastic behavior of the sample. More information on rheological measurements and specifically on the strain controlled amplitude sweep can be found for example in [1].

From the tribological side, friction at a certain sliding speed and static friction are relevant for a good performance of the greases. Greases are used to eliminate noise and to guarantee a smooth movement. In order to measure static friction, the friction force at which the system is starting to move has to be determined. This is similar to the yield behavior in rheology where the stress value is measured when the sample is starting to move. The friction behavior itself is normally presented in Stribeck curves which correlate the friction coefficient with the sliding speed, the viscosity and the normal load.

2 Background on Stribeck curves

In tribology, speed-dependent film formation and changes in the frictional properties are portrayed through so called "Stribeck curves". Stribeck was a German scientist and engineer, living from 1861 to 1950, who investigated the film forming properties of lubricants in journal bearings, and found a distinct correlation between frictional properties and films of lubricant formed between two surfaces [12]. He observed, as shown in Fig. 1, that, at low speeds, it is mainly the two surfaces that interact and determine the friction (boundary friction). The friction is represented by the coefficient of friction, μ, which is the ratio between the frictional force F_F and normal force F_N. With increasing speed, the lubricant is transported into the space between the surfaces and uplifting forces of the lubricant start to push the surfaces apart (mixed friction). The further the surfaces are pushed apart, the lower the friction. The minimum friction is reached when the surfaces are just no longer touching. This regime is called elasto-hydrodynamic friction. If films are formed, they prevent or reduce wear. When the sliding speed is further increased, the film thickness increases. Just like a flow curve, the internal friction of the lubricant will then increase and thus the friction of the entire tribosystem increases again (hydrodynamic friction).

These principles, even so investigated for journal bearings by Stribeck, can be extended to other tribo-systems, to characterize the correlation between frictional properties and friction regimes and film formation. The method can be used for screening purposes. A whole range of information can be gathered from a model test depending on differences observed between the investigated samples.

As the boundary and first parts of the mixed regime are mainly determined by the interactions between the two surfaces, static friction and low speed properties, the impact of additives and dispersed materials, and adhesive interactions can be analyzed in this regime. In the remaining mixed and (elasto-)hydrodynamic regime, the high speed properties, film formation and the impact of rheological properties of the lubricant can be determined.

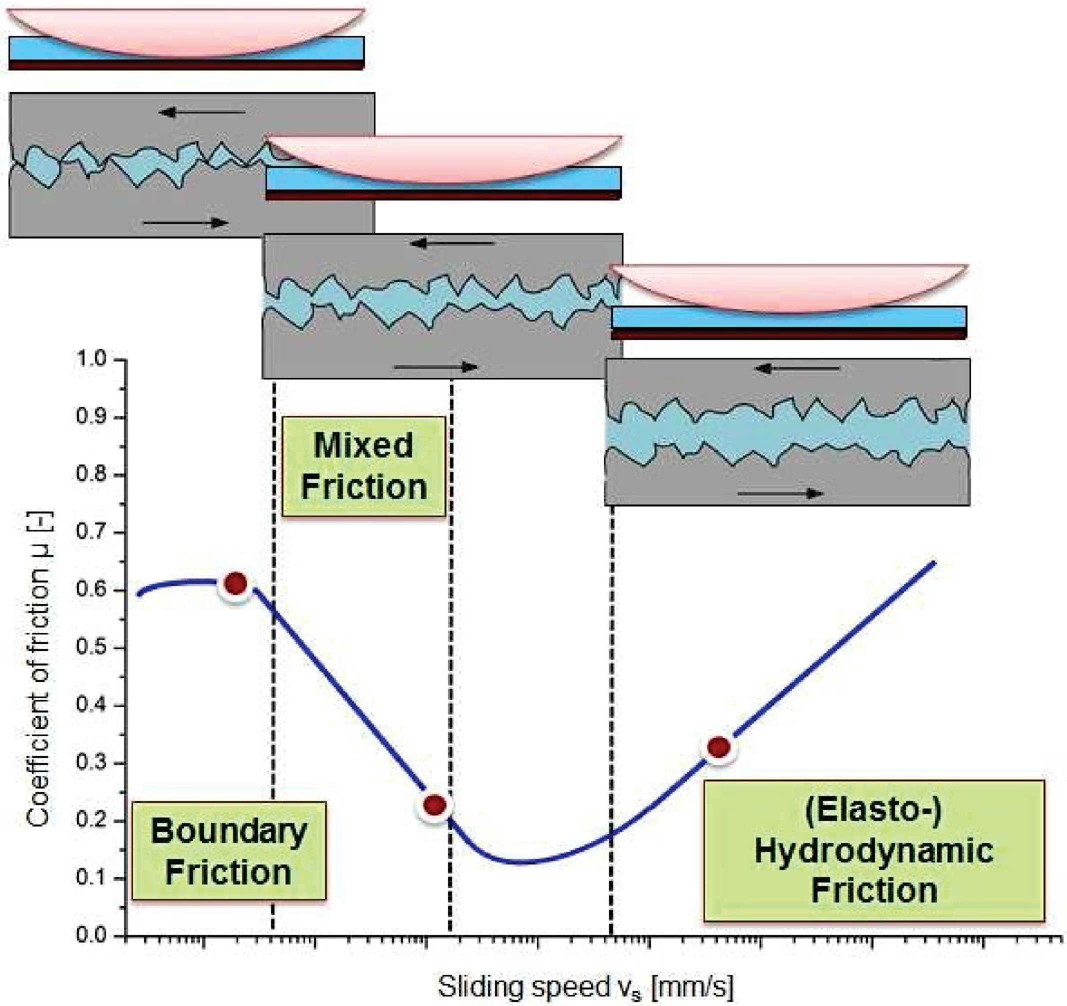

Figure 1: Schematic diagram and princples of Stribeck curves.

4. Instruments and Methods

4.1 Rheometer

An MCR 302 rotational rheometer from Anton Paar was used for all tests. The rheometer employs an air bearing supported electronical commuted synchronous motor (EC- Motor) [5]. The electronical commutation represents a non contact way to excite the rotor and can be used in combination with an air bearing thus enabling measurements at low torques. The EC-motor is sometimes called a brushless DC motor, since the motor current is commutated electronically and there are no brushes or contacts to excite the motor, but rather the motor is excited by special permanent magnets with a high flux density. It is a synchronous motor because the rotor rotates at the same speed, i.e. synchronous, with the stator field. The rotor field is produced by high energetic permanent magnets, which are mounted at fixed positions on the rotor. Since the positions of these permanent magnets are known, the rotor field is known. The EC control makes use of this knowledge. It is possible to adjust the electro-magnetical torque in such a way that it is linear to the total amount of the stator current, i.e. $M \sim I_s$. The applied electrical current is a direct measure of the torque. In addition, an optical encoder measures the angle and the speed of the rotational movement.

The instrument controls the rotational speed and measures the resulting torque very accurately. Force controlled measurements are possible by applying a torque and measuring the resulting speed. The normal force can be set and recorded during all tests. The MCR 302 rheometer used here features the following measurement ranges: rotational speed: 10^{-6} to 3000 rotations per minute (rpm); torque: 10^{-7} to 0.2 Nm; normal force: 0.01 to 50 N.

4.2 Temperature control

For controlling the temperature during the test, a Peltier temperature control system was employed. It consists of a Peltier controlled bottom plate and an additional Peltier controlled hood. In Fig. 2 a rheometer and the temperature control system are displayed.

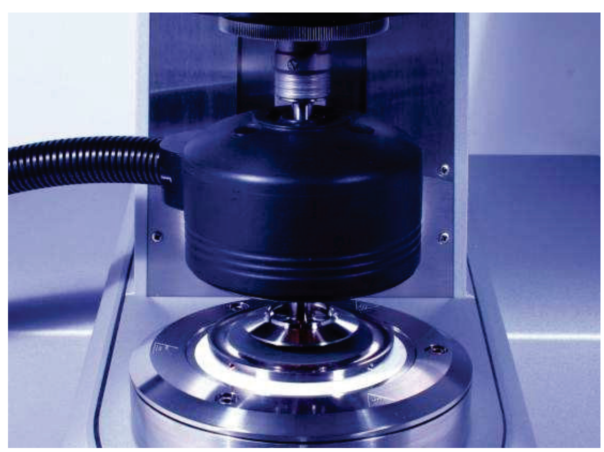

Figure 2: MCR Rheometer and Peltier system with a temperature controlled hood.

The additional use of a Peltier controlled hood ensures a uniform temperature distribution within the sample over the whole measurement range. This is crucial since a temperature gradient within the sample will induce misleading results, as it occurs when for example only the lower plate will be temperature controlled [6]. The same temperature control unit was used for both rheological and tribological measurements.

4.3 Rheological and tribological measuring setup

For rheological measurements a parallel plate measuring geometry with 25 mm diameter was used. The sample was placed within a 1 mm gap between the bottom and the upper plate.
The tribological properties were investigated with the help of an accessory which is mounted onto the MCR rheometer. It makes use of the large measurement ranges as well as the motor control mechanism of the rheometer. The setup has been described in detail elsewhere [7].
Here, only the main parts are mentioned. The device is based on the ball-on-three-plates- principle (or ball-on-pyramid) wherein the geometry consists of a steel ball which is held in a measuring shaft, and an inset where three plates can be placed. This inset is fixed on a bottom stage that is movable in all three directions. The ball-on-three-plates setup has been used before in a dedicated device to measure static friction coefficients [8]. Fig. 3 and Fig. 4 depict the tribometer setup schematically and in photos, respectively.

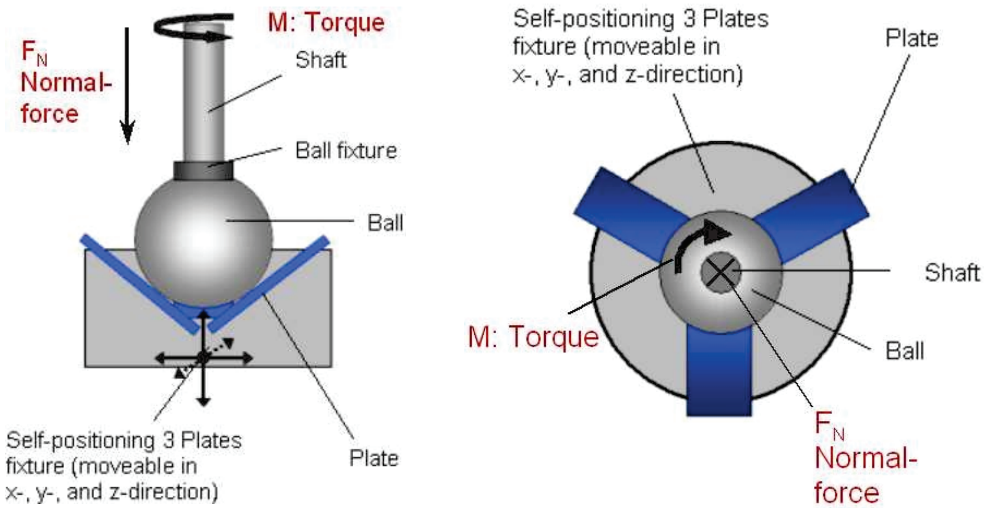

Figure 3: Schematic setup Tribology accessory in side and top view. The torque and the normal force applied by the rheometer are indicated by arrows.

Figure 4: The Tribology accessory

The flexibility of the bottom plate is required to get the same normal load acting evenly on all the three contact points of the upper ball. The rotating sphere is adjusted automatically and the forces are evenly distributed on the three friction contacts. The ball as well as the plates for the inset can be exchanged so that the system can be adapted to desired material combinations.

The rotational speed applied to the shaft brings the ball to slide against the plates at the contact points. The resulting torque can be correlated with the friction force by employing simple geometric calculations. The normal force of the rheometer is transferred into tribological normal force acting perpendicular to the bottom plates at the contact points.

The relations between the normal force (F_N) and the torque (M) of the rheometer to the tribological normal force ($F_{N,tribo}$), the force perpendicular on each sample plate, and the friction force (F_F) experienced by each sample are:

$$F_{N,tribo} = F_N/(3 \cdot \cos\alpha),\ F_F = M/(3 \cdot \sin\alpha \cdot r_{ball})$$

with r_{Ball} being the radius of sphere and α the angle of the plates, respectively. The following dimensions have been used: $\alpha = 45$, r_{ball} = ½ inch = 6.35 mm. Based on the geometrical dimensions the tribological properties can be calculated. The rheometer used as a tribometer has the following measurement ranges (per plate): Normal Load: 0.3 to 23 N; Friction Force: up to 19 N; Sliding Speeds: 10^{-8} to 1.41 m/s.

5 Impact of Rheology on Film Formation

The rheological properties of grease, mainly the viscosity, are a crucial factor for lubricant film formation. The inner friction of the lubricant determines how the lubricant flows through a gap of a tribological contact. On a curved surface the lubricant induces forces on the surface creating uplifting forces that counteract the normal force on the tribo contact, as depicted on Fig. 5. For more details, please see publications on the topic, e.g. [13].

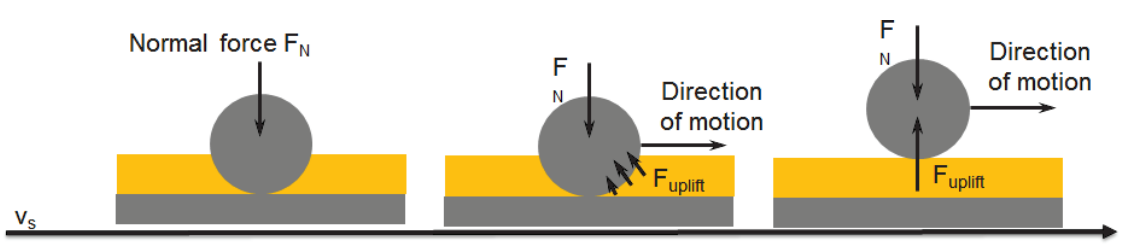

Figure 5: Basic principles of lubricant film formation

The higher the viscosity, the stronger is the uplifting force, which has two main effects on the shape of Stribeck curves:

1) Earlier transition into mixed lubrication
2) Earlier transition into hydrodynamic lubrication

as shown in Fig. 6 for measurements of a semi-synthetic base oil at different temperatures and thus different viscosities. Herein, the viscosity increases with decreasing temperature. Stribeck curves were measured by increasing the sliding speed logarithmically from 0.04 to 500 mm/s, a tribological normal force of 1.5 N and temperatures of 25 °C, 10 °C, 0 °C, -10 °C, and -20 °C.
As can be seen from the measurements, mixed lubrication, and hydrodynamic lubrication regimes shift to at lower sliding speeds with decreasing temperature, i.e., with increasing viscosity.

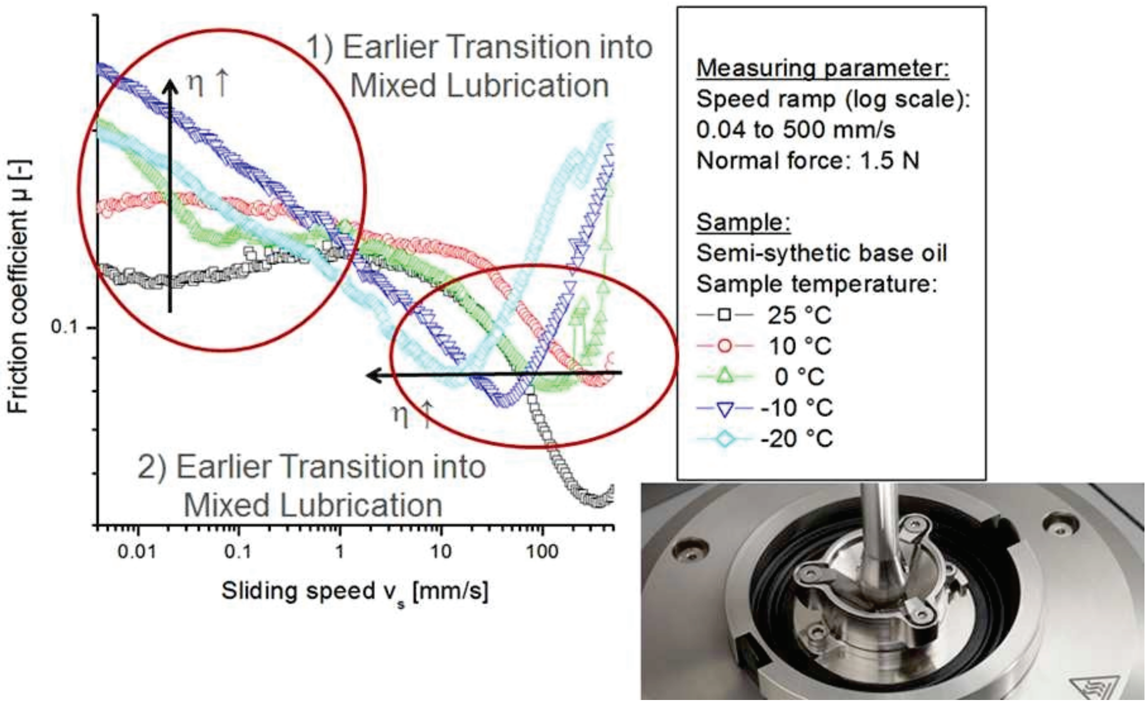

Figure 6: Viscosity dependence of Stribeck curves

6 Impact of Rheology on Static and Boundary Friction

In addition to the obvious dependence of lubricant film formation on rheological properties, static and boundary friction also depend on rheological properties of greases. Contact conditions, static friction values and the interacting forces between two specimen surfaces in boundary friction depend on structural properties of greases.
Yield stress of the grease determines how close one specimen gets to the other when a defined normal force is applied. If the yield stress is not exceeded by the forces in squeeze flow between two specimens, the lubricant film remains. Fig. 7 shows results from an experiment comparing two complex structured fluids with different yield points. The friction coefficient is plotted as a function of sliding speed and the change of ball position during the experiment, named "gap", is also plotted as a function of sliding speed. It can be seen that both samples start with a significant film between the specimens. After overcoming the static friction (dotted line), the lubricant is transported out of the gap, the gap height is decreasing, and the specimens approach each other. So, the starting conditions are different. Different initial film heights are observed at test start. In the most extreme case, this could mean that in one case the specimens could be in physical contact at test start and the specimens with a comparison sample could feature a lubricant film.

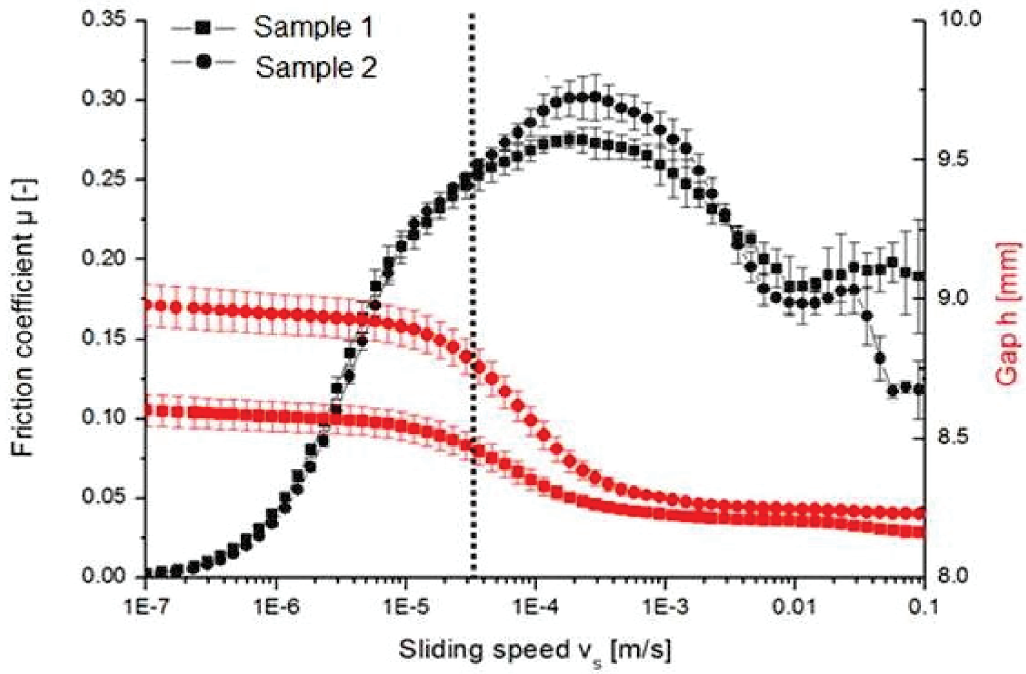

Figure 7: Investigation of lubricant film formation in tribo-contacts

Further, in the presence of grease at the contact, the static friction value itself depends on the yield point of the grease. To overcome static friction of a tribo-contact with grease, the interacting forces between the specimens and the inner friction of the lubricant, that is connected to the specimens, must be exceeded. Fig. 8a shows rheological amplitude sweep measurements of four greases. The greases were characterized at 25 °C with a deflection sweep from 0.01 % to 100 % with a frequency of 10 rad/s.

In Fig. 8b static friction measurements of steel-steel tribo-contact for the four greases as lubricant are shown. The static friction was determined at 25 °C and with a normal force of 1.5 N. The torque of the measuring setup was increased logarithmically from 0.01 mNm to 100 mNm. The sliding distance was measured as a function of the applied torque. The static friction value was determined at the point where the sliding distance sginificantly increased. The different greases show strong differences in their yield points. Grease sample #4 features a storage moduli significant smaller than the other samples, which does not strongly affect the static friction properties. The yield stress and static friction sequence is as follows: #1>#2>#3>#4. Static coefficients of friction can be clearly distinguished. Sample #1 and #2 are close, as are #3 and #4, both in the rheological as well as the tribological properties. Thus, the yield point of a grease impacts the static friction significantly. The magnitude of the yield stress has a strong impact on the static friction of a tribo system which clearly points to the fact that rheological measurements are crucial for an interpretation of tribological data.

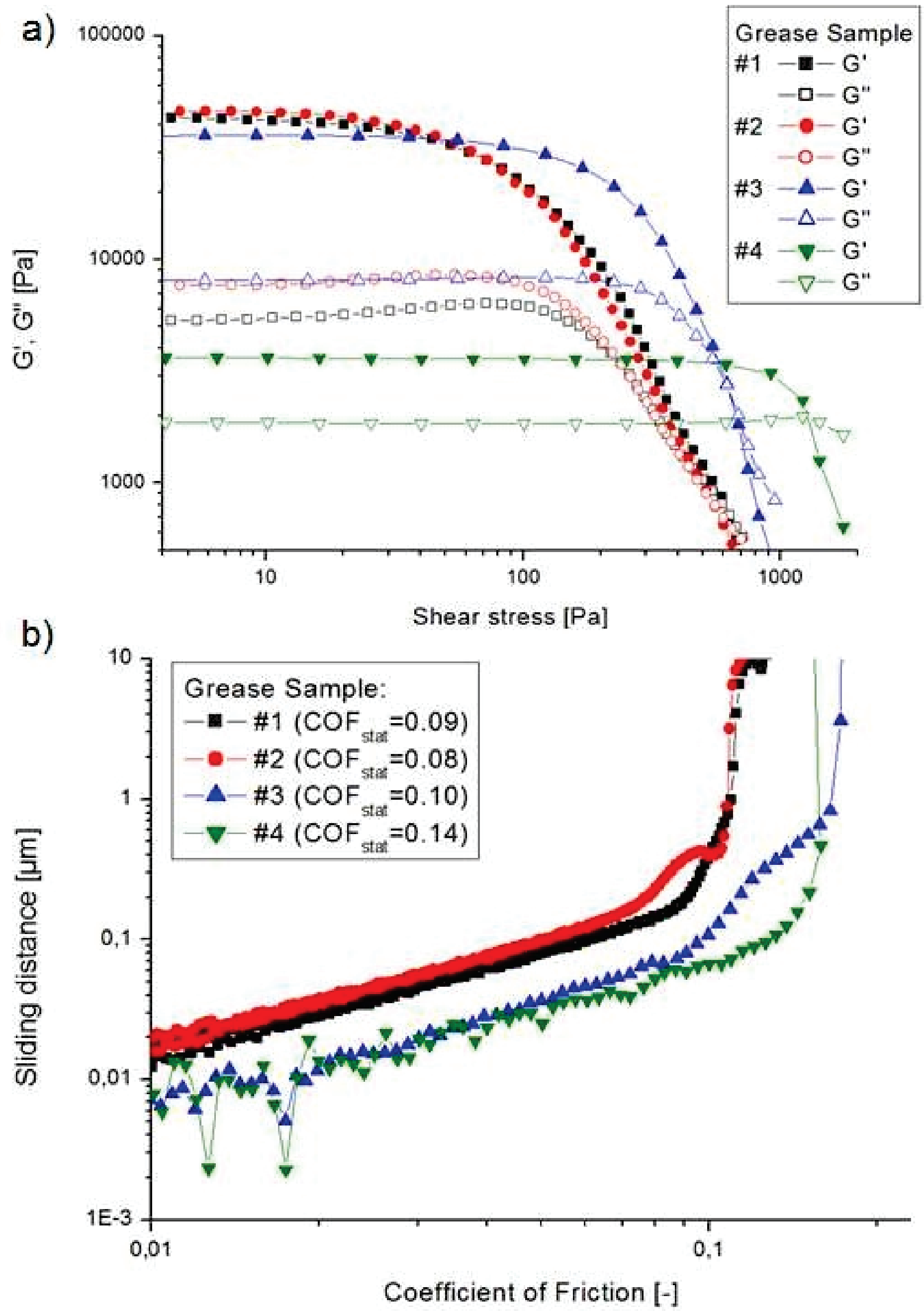

Figure 8: Yield stress dependence of static friction in a tribo-contact containing grease. a) Yield stress determination with amplitude sweep method. b) Static friction determineation of steel-steel tribo-contacts containing the greases tested rheologically.

7 Conclusions

Rheological properties of lubricants, especially greases, have a strong impact on the tribological properties of a tribo system. Viscosity determines the film formation properties, while the yield point of grease determines the contact conditions in a tribo-contact and impacts the static friction significantly. Thus rheological and tribological measurements complement each other. Rheological measurements are necessary to be able to interpret the findings in tribological measurements.

Model measurement, like Stribeck curves hold a great potential to screen greases efficiently and to gather extensive information about grease performance in a fast and simple measurement. These measurements can be performed on tribometers employing rheometric measuring drives. These allow for the precision motion necessary to cover the speed range necessary to measure Stribeck curves from static friction to full lubricant film formation. Furthermore, these devices allow for measurements of both rheological and tribological properties on a single test equipment.

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High Performance Poly-urea Grease for the Indurating Machine at Pellet Plant – A Case Study

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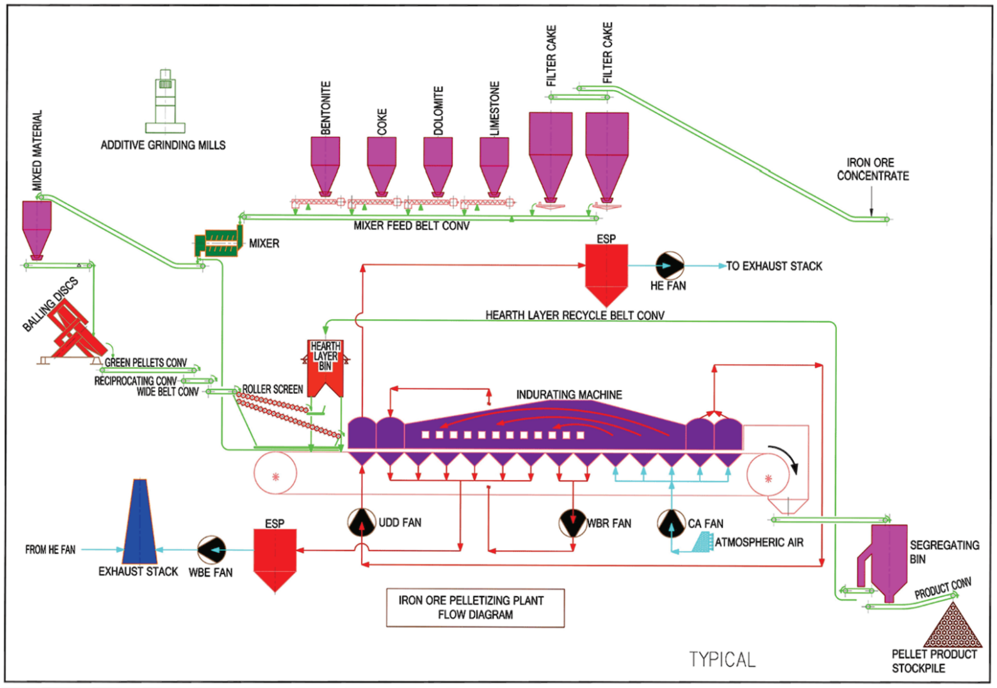
Carl Bechem Lubricants- AnirbanKumbhakar and SantanuDutta.

Abstract

The Pellet Plant was commissioned in the year 2011.It was established to increase hot metal output to meet 10MTPA crude steel production. The plant was supplied by OUTOTEC and its capacity is 6 mill tons of pellet per year.
GREASE - A had been running since the day of inception of the Pellet plant at the travelling grate furnace slide track and hood sealing. This is mineral oil based lithum Complex thickened NLGI 2 grease with base oil viscosity 220 which can sustain temperature upto 150°C.There was problem of softening of grease at elevated temperature. Also grease was dripping at firing zone in the Indurating furnace area which posed fire hazard. A polyurea thickened NLGI 1.5 grease with base oil viscosity of 490 has been introduced to overcome problems with the existing grease.
Tata Steel and Carl Bechem Lubricants jointly studied the whole application and recorded the parametersaffected by this change over. Pump operating pressure and ELPS residue pressure as well as all DM valves were checked during this process and the ones with leakage were recorded. Also Grease comparison study between old and new grease was done before implementation.

Introduction

Pellet plant was put up to use iron ore fines which are not suitable for Sinter making, these fines are transformed to spherical lumps of uniform size that can be directly fed to the blast furnace for Iron making. The benefits of pellets are fast reduction and high metallization rate.
The Typical Layout of the Process is shown below.



After forming the green pellets, the process requires a travelling grate furnace for hardening. To avoid emission of gas from the furnace to the ambience, the furnace is usually running with a gas pressure slightly below ambient pressure. This bears the risk of false air entering the furnace resulting in difficulties to reach the required process temperature.

To avoid entrance of false air to the furnace atmosphere lubricating grease is pumped via central lubricating system into the gaps in-between grate cars and housing to block any gas flow. Another important purpose of the grease is to provide lubrication in between the moving grate cars and the fixed housing and, thus, to avoid wear and to lower the power consumption. A sketch of the supply of the sealing grease is given in Figure 1.

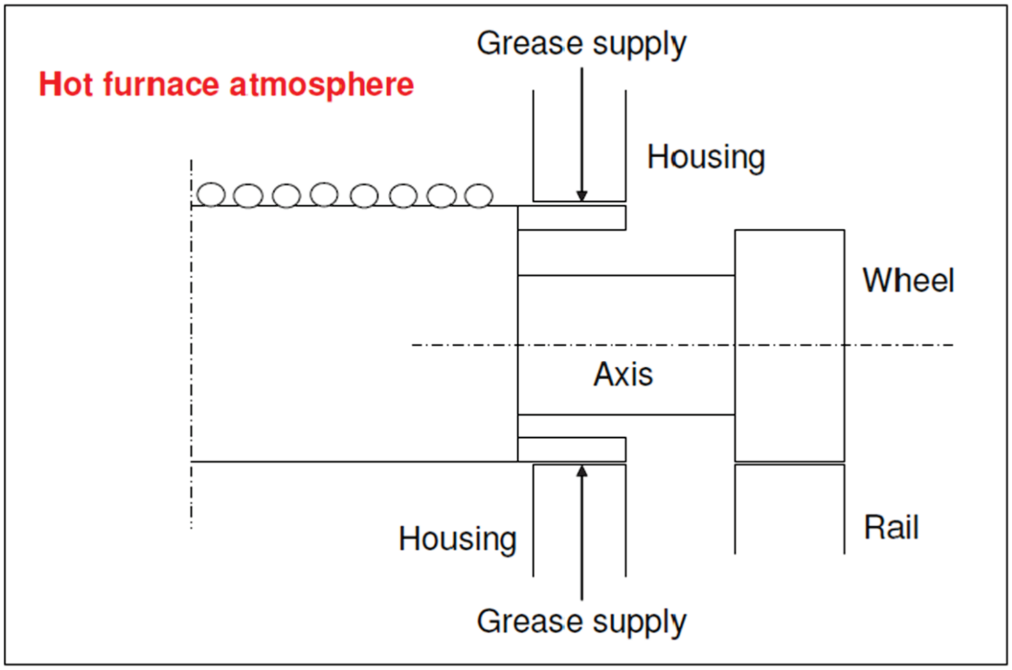
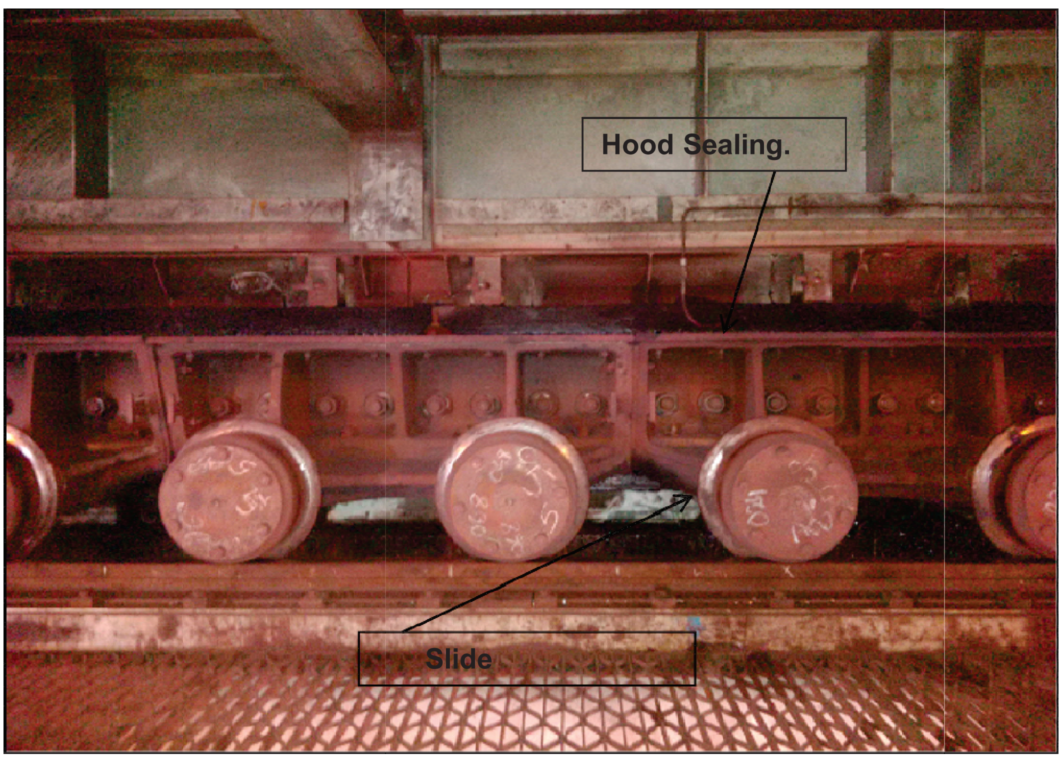
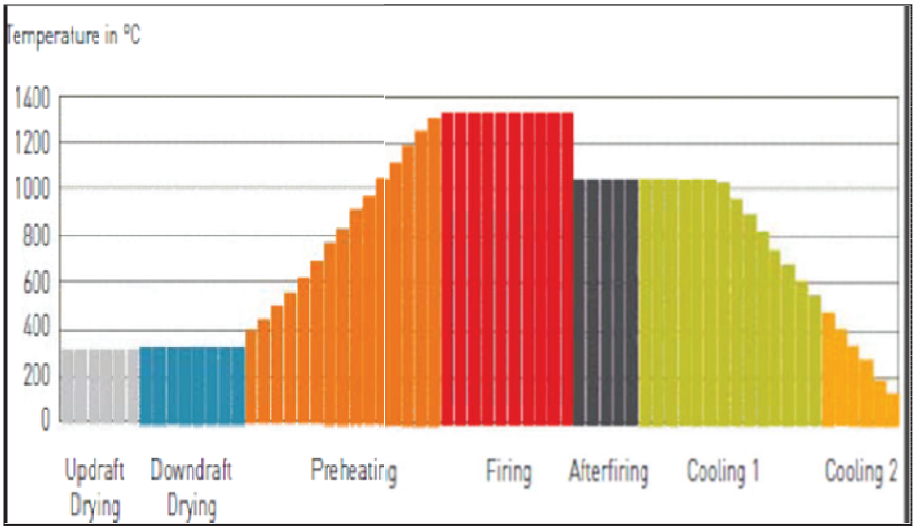


Figure 1: Sketch of sealing grease supply

Pictorially this can be depicted as below.



The typical temperature range in the Indurating furnace is shown below zone wise. We can see that the Minimum temperature is somewhere close to 180°C to Maximum 1300°C.



Effect of Operating Temperature on Grease

Greases behave differently at elevated temperatures. They cannot provide stable properties over a wide temperature range. Since temperature has a very strong impact on the viscosity of oil and more than ⅔ of the grease is oil, temperature will definitely influence the grease also. The typically observedProcesses once greases are going through temperature changes are to be found in Figure 2.

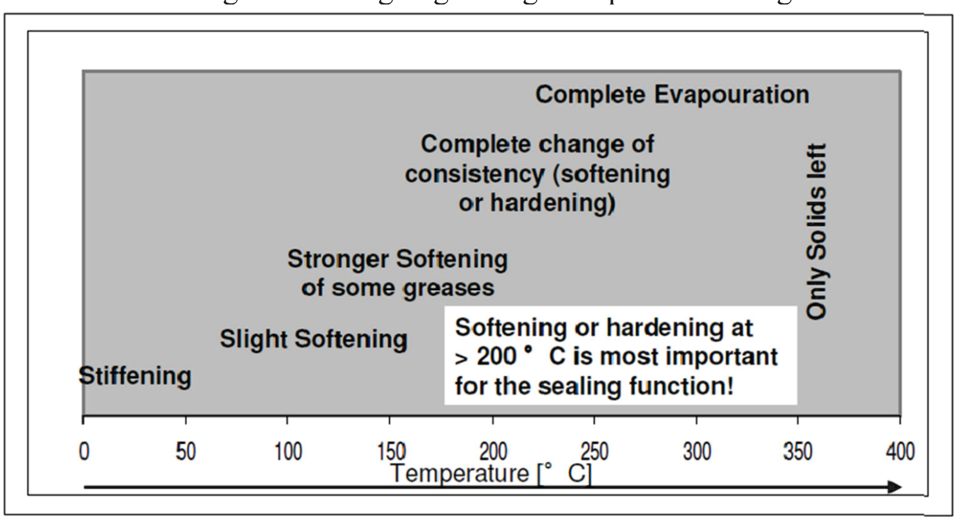


Figure 2: Influence of temperature on lubricating greases

Typically the consistency of greases is measured at 25 °C and their base oil viscosity is given at 40 °C. For temperatures lower than this, the viscosity of the base oil will increase drastically resulting in stiffening of the grease once temperatures are getting close to zero degrees centigrade. For temperatures of more than 40 °C the base oil viscosity will decrease resulting in slight softening of the grease.

At a certain temperature somewhere in-between 100 °C and 200 °C some grease will even show a stronger softening or even will become rather liquid. This depends on the type of thickener, characteristics of other ingredients, the time the grease is exposed to that particular temperature and other factors. For few lubricating greases, this softening is hardly observed.

However, at even higher temperatures a complete change of consistency will occur sooner or later. Most of the thickeners will disintegrate and the grease will become fluid. Only very few greases will not soften. Unlike the others, they have rather more tendency to stiffen and will become paste-like. Such paste will provide excellent sealing of the gap in-between the housing and the travelling grate car. Therefore, greases stiffening at high temperatures are very much recommended to be applied as sealing greases for travelling grate furnaces.

Nevertheless, no grease is capable to withstand temperatures of 300 °C and more, therefore, finally the grease will burn-off or evaporate leaving only a very small part of solid ashes.

In some plants, standard EP 2 grease with lithium thickener is applied for the sealing of travelling grate furnaces. According to Figure 3 these products are completely unable to maintain a proper sealing function. Up to 180 °C,certain stiffness may remain but at 200 °C they will become completely liquid and pour from the gap. This requires a huge amount of grease to be pumped. The fresh grease needs to enter faster than it is becoming liquid, otherwise the gap is open and false air may enter the furnace.

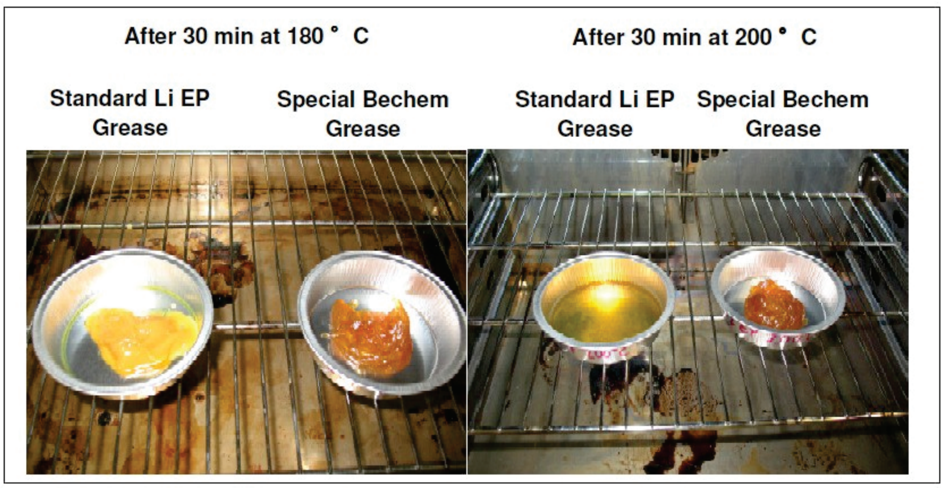


Figure 3: Greases at high temperatures

A stiffening grease, as it was described earlier, does not require such extremely high re-lubricating rates since the paste-like heated grease on the inner side of the gap creates a protecting barrier to separate the hot gas from the fresh grease on the outer side of the gap. Therefore, less re-lubrication is required to maintain both, sealing and lubrication of the gap.

Thus, following advantages are achieved:

- better sealing properties and, therefore, higher process stability since the risk of the entrance of false air is excluded
- less wear on the sliding plates of cars and hood resulting in lower spare part costs
- lower power consumption, thanks to better lubrication and reduced friction in between cars and hood
- lower lubrication cost by clearly reduced lubricant consumption
- less contamination of the ambience due to grease leaking from the gap

GREASE - A, product that was applied earlier, was giving better sealing properties than standard lithium EP greases do. Nevertheless, due to the fact that it is soap thickened, it will definitely undergo a softening process once it becomes overheated.
This may be found in Figure 4, where comparisons of GREASE - A and the high- temperature lubricating grease GREASE – B is given. After being heated to 200 °C GREASE - A is becoming rather soft. A major part of it is already liquid.The remaining consistent part is very soft and not capable of providing sufficient sealing properties.

Standard Lithium Grease at 200°C

Poly Urea Grease at 200°C.

Recommendation

Based upon the above study conducted by both TATA STEEL and CARL BECHEM, GREASE - Bis now being used.
GREASE – Bis a mineral based high-temperature grease. It is thickened by tretraurea,the polyurea type with the longest chain length applied in lubricating greases. The extraordinary high-temperature properties described above are mostly given by this thickener. Additionally, the high base oil viscosity helps a lot to provide

best lubricating properties. The base oil of GREASE – Bis more than two times more viscous than the base oil of GREASE - A.

Due to the higher base oil viscosity a higher pressure loss of the grease flow inside of the pipes of the lubricating system is to be expected. For compensation, the consistency of GREASE – Bis a little lower (1.5 in place of 2). After reaching the lubricating spot and being heated, consistency will increase to provide the best sealing effect.

Results

Before the initiation of trial, 4 KPI were set to measure the performance changes resulting from this changeover.

1. Change in Current Rating of the main motor of Indurating machine.
2. Change in specific heat consumption for heating the Pellets in Indurating Machine.
3. Change in Off Gas temperature at suction box (If recycling being done with same gas for further heating of Pellets it will reduce energy consumption).
4. Change in Lubrication Consumption.

Change in Motor current of the main motor

It can be seen from the trend that motor current has dropped by 5 to 6 Amp.

Date	Time	Current reading(in Amps)	
		Mean	Maximum
01.08.14		107	124
03.08.14		106	124
04.08.14		106	127
05.08.14		106	122
12.08.14	2:00 AM	105	125
	4:00 AM	105	125
	6:00 AM	105	125
	10:00 AM	105	125
	2:00 PM	105	121
	6pm	105	121
	10:00 PM	105	127
13.08.14	2:00 AM	105	127
	6:00 AM	105	126
	10:00 AM	105	122
	2pm	105	120
	6pm	105	120
	10:00 PM	103	117
14.08.14	2:00 AM	103	117
	6:00 AM	103	119
18.08.14		104	120
19.08.14		103	118
22.08.14	6pm	106	118
	12.pm	105	118
23.08.14	6:00 AM	104	115
	6:00 PM	104	114
24.08.14	6:00 AM	105	115
	6:00 PM	104	117
25.08.14	6:00 AM	99	117
	6:00 PM	104	117
26.08.14	6:00 AM	104	117
	6:00 PM	104	118
27.08.14	6:00 AM	103	118
03.09.14		103	114
04.09.14		103	118
05.09.14		0	118
06.09.14		102	114
07.09.14		102	116
08.09.14		103	117

Change over to GREASE – B .

The Change in specific heat consumption for heating Pellets.

This parameter is being monitored by TATA steel Operation peoples internally.

Changes in Lubrication Consumption

In the entire system the numbers of lubrication points are mentioned as under. For

Hood Seal: 52
For Slide track: 396
Total: 448 points

Per cycle O/P: 3360 cc=3360x0.9
= 3024 gms
= 3.0 kg

As per earlier cycle
Pump on:8mins(Line A)
Pump on: 8 mins(Line B)
Pause : 10 mins
Total Cycle Time: 26 mins
So the number of cycle in a day: 55 cycle
Per Month O/p= 55x3024gmx30 days
=4989.6 kg
=28 barrels
Present Cycle
Pump On: 8 mins(Line A)
Pause : 10 mins
Pump on: 8 mins(Line B)
Pause : 10 mins
Total Cycle time: 36 mins
So number of Cycle in a day: 1440/36
: 40 cycles
Per Month O/P: 40X3024gmx30 days
: 3629
: 20 barrels

Total savings: 8 barrels per month.

There was savings of 28% in the grease consumption from previous pattern of consumption.

Conclusion

Following problems were observed with earlier grease (mineral oil based Lithium NLGI 2 grease and base oil viscosity 220).

1. Excess consumption of grease.
2. Grease was melting and creating spillage which was fire hazard.
3. Grease was not able to provide complete sealing since the temperature was very high in the sealing area.
4. Higher temperature was also resulting in in-effective lubrication of slide bar and pellet car causing excess consumption of power for the indurating machine.
5. Problem in pumping NLGI 2 grease.

Looking into above problems, a polyurea thickened grease with NLGI 1.5 and base oil viscosity of 490 has been introduced and following advantages have been observed after implementation.

1. Reduced grease consumption without affecting other parameters.
2. No Spillage or softening of grease is observed.
3. Sealing has improved.
4. Reduction in energy consumption for induration machine.
5. No pumping problem through centralized lubrication system.

Development Of A Multi-Complex Calcium Sulphonate Grease With Enhanced Water Resistance For Steel Plant Applications

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Abstract

Steel plant grease applications frequently involve lubrication of bearings with heavy ingress of water/ emulsions for in-process requirements. Greases in such applications, besides being subjected to high temperatures and heavy/shock loads, are also required to possess outstanding resistance to water washout and water spray-off. One such application is lubrication of roll-neck bearings of rolling mills in steel plants. Lithium extreme pressure greases have conventionally been used in these applications with inherent limitations of poor structural stability, deficient water resistance and extremely short re-lubrication intervals. More recently, high dropping point lithium complex and calcium sulphonate greases with inherent load bearing capacities have been successfully employed with improved performance. However, in case of heavy water ingress, even these greases fail to withstand the rigor of a complete replacement cycle, thereby resulting in premature shut-down and loss of efficiency of the plant. A new multi- complex high dropping point calcium sulphonate grease with significantly improved load bearing capacity, water washout and water spray-off characteristics has been developed specifically for steel plant applications involving heavy ingress of process water and emulsions. During protracted trials, this grease has shown significantly improved performance as compared to the normal lithium complex and calcium sulphonate greases.

Introduction

Lubricant rheology plays an important role in controlling energy losses in hydrodynamically lubricated contact surfaces, the situation becomes aggravated in presence of water ingress. Over the years Lithium EP, Lithium complex greases have been used in roll neck bearing of steel plants where the speed, shock loads and heavy water ingress are encountered. When faced with the challenges of reducing bearing loss/ damages in such operation using optimum quantity greases authors' laboratory has come out with a unique multi complex calcium sulphonategrease (MCS)for such steel mill applications.

The speed, shock load ,showering mill water and the thermally stressed conditions are encountered in the roll neck bearings of steel plant rolling mill. The failure causes for such bearings used in rolling mill are water related wear, flaking and rust . Due to high speed and heavy water ingress,some water gets trapped inside the bearings along with the greases which affects the normaltribochemistry of the conventional greases.

Due to large centrifugal forces, a good amount of grease comes out of the bearings as well. We have come out with a developed grease, a multi complex calcium sulphonateto take care of all these factors effectively.
We have processed a multi complex calcium sulphonate grease incorporating some amount of alkaline metal phenate and /or boron-amine adduct into the miceller moiety to render better adhesiveness , load bearing capability as well as spread-ability under stressed conditions without compromising water absorptivity. The grease can perform well in thermally stressed heavy loaded conditions also.

Consideration

Typical miceller structure of the system is unique with water absorption capabilities. Its strong adhesion to metal surface repels water ingress to the surface of the metal. It resists squeeze out and thinning.It has an excellent spreading ability that ensures all critical wear zones are covered. It retains complete lubricant coverage without affecting mechanical freedom. It has a buffer action which shows reserve alkalinity. So it is also resistant to acidic and alkaline environment where pH may vary from 5 to 10. It is also resistant to salt water. It rapidly absorbs and dissipates heat. It is a superior sealing grease with high capability of keeping water and abrasive foreign particles out of contact with excellent oxidation stability thus maintainingtheworking life of bearings. In short, the grease renders long time lubrication in thermally stressed operating conditions.

Critical Properties of the MCS grease targeted for the trial to meet the severe application requirements of the Roll Neck bearing are appended below:

- Improved Water Resistance
- Improved load bearing capability (water related wear)
- Improved adhesivity
- Improved spreadabliity
- Improved Stay-in grade properties / structural stability
- Preventing Seizure of bearing
- Improved pumpability

MILL OPERATING PARAMETERS	
Type of Mill	: 6 Hi Cold Rolling Mill 1050 width.
Speed of Mill	: 1200 metres per minute
Name of Machine Manufacturer	: FPE –CMI
Application area	: Work roll and intermediate roll neckbearings
Type of Bearing	: 4 Row Taper Roller bearing
Size of Bearing	: InternalDia , 215 mm - 234mm
Make of Bearing	: NSF-STF 215 and STF -234
Operating Temperature	: Up to 120 deg. C,
Operating Load	: Work roll- per bearing almost 80 MT and intermediate roll almost 40 MT

Results and discussion

TABLE-1

COMPARATIVE STUDY ON PHYSICO-CHEMICAL PROPERTIES

Sl.No	Parameters	Method ASTM	Lithium - EP	Lithium Complex	Calcium Sulfonate (CS)	Multi Complex Sulfonate (MCS)
1	Appearance	Visual	Smooth & Buttery	Smooth	Smooth & Tacky	Smooth & Tacky
2	Consistency	D 217	NLGI-2	NLGI-2	NLGI-2	NLGI-2
3	Dropping Point, deg C	D 2265	198	279	> 320	>320
3a	Dropping Point, deg C after mixing with 10% water	D 2265	140	226	>320	>320
4	Roll Stability @ 80 deg. C, PEN Number Change, %	D 1831	-			
	8 Hrs.		11	12	8.5	5
	16 Hrs.		13	14	10	7
	24 Hrs.		15	16	10.5	8.5
	32 Hrs.		18	19	12	9
5	Water Washout @ 80 deg. C, % washed out, mass	D 1264	3.5	2.2	0.8	0.3
6	Water Spray off @ 38 deg. C %, 20Psi	D 4049	32	45	25	21
7	Four Ball Weld Load, kgs.	D 2596	250	315	500	620
8	Do, after mixing with 10 % water		160	200	500	620

MCS grease shows superior properties of the parameters checked. It is also observed, when grease is mixed with 10% water, in case of Lithium-EP and Lithium complex greases dropping point and four ball weld load values drastically deteriorated from the original values. Whereas, CS and MCS greases were not affected in presence of water. It clearly indicates that in presence of water MCS grease perform best among the four greases studied.

Based on the above findings, we have carried out extensive studies to understand the effect of water and emulsions used in rolling mill on the various properties of the greases CS and MCS, which are tabulated in Table-2

TABLE-2

Water spray off test (ASTM D 4049)

(% water sprayed off)

Sl.No	PARAME- TERS	C S			MC S		
	CONDITIONS	20 PSI	30 PSI	40 PSI	20 PSI	30 PSI	40 PSI
1	With tap water @ 40 deg C	25	31	38	20	24	28
2	With 5% Emulsion @ 40 deg C	23	32	37	20	25	26
3	With 5 % Emulsion containing 20 ppm Fe dust at 40 deg C	21	25	35	18	25	21

Emulsion :Non ionic emulsion used (as used in the mill)

The Table-2 shows that the water spray off properties of the two greases are unaffected with emulsion and emulsion containing iron dust even at higher pressure conditions. The results indicate that the MCS grease can effectively resist water, emulsion as well as iron dust (simulated mill water conditions).

TABLE -3

EMULSION ABSORPTION TEST - (DEF STAN 91-27/2 Annex B, % Mass)		
Parameters	CSC	MCS C
With 5% Emulsion - Absorption , %	92	97

From the above study it is clear that the CS greases having higher potential to absorb mill water mainly because of its unique lipophilic properties associated with its miceller structure.

TABLE -4

EMCOR RUST TEST		
Parameters	CS	MCS
Rating, with distilled water	0,0	0,0
Rating, with 5% emulsion	0,0	0,0

The above results(Table 3) indicate that CS greases can absorb/ emulsify significantly more water without collapsing the structure; which is corroborated with the dropping point results as indicated in the TABLE-1. In a stable water-in-oil emulsion there are surface active components stabilizing the reverse micelles. Here the miceller structure of the complex moiety acts as a surface active component. The water will interact with the surface active moiety and become restricted in its mobility lowering its self-diffusion constant. It is more prominent in case of MCS.
The effect of water on the apparent viscosity which is a measure of the degree of structure of grease was determined at a shear rate of 1/sec @ 25 deg C. It is observed that there is no lowering of viscosity when grease is mixed with 10% water. (Viscosity Pa.S 750 with no water and 835 with 10% water mix grease.

Trial observations

No pumping problem faced during the trial

No bearing failure during the trial period. Bearing never found running dry even in bad seal conditions Drastic reduction (75%) in downtime is observed till date.

Benifits

Bearing life seems to be increased more than double .(FinalConclusion can be made after continuous cycles of 6 months).

Substantial reduction in downtime

Consumption reduced upto 15% when compared to Conventional CS grease.

Conclusion

The developed grease, MCS, not only prevents rust but also effectively controls the development of uneven wear in the bearings ,as there is no bearing failure till date. So it is very economical towards the consumption and the energy consumption point of view.This grease can be tried out in several other equally severe applications in steel plants.

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