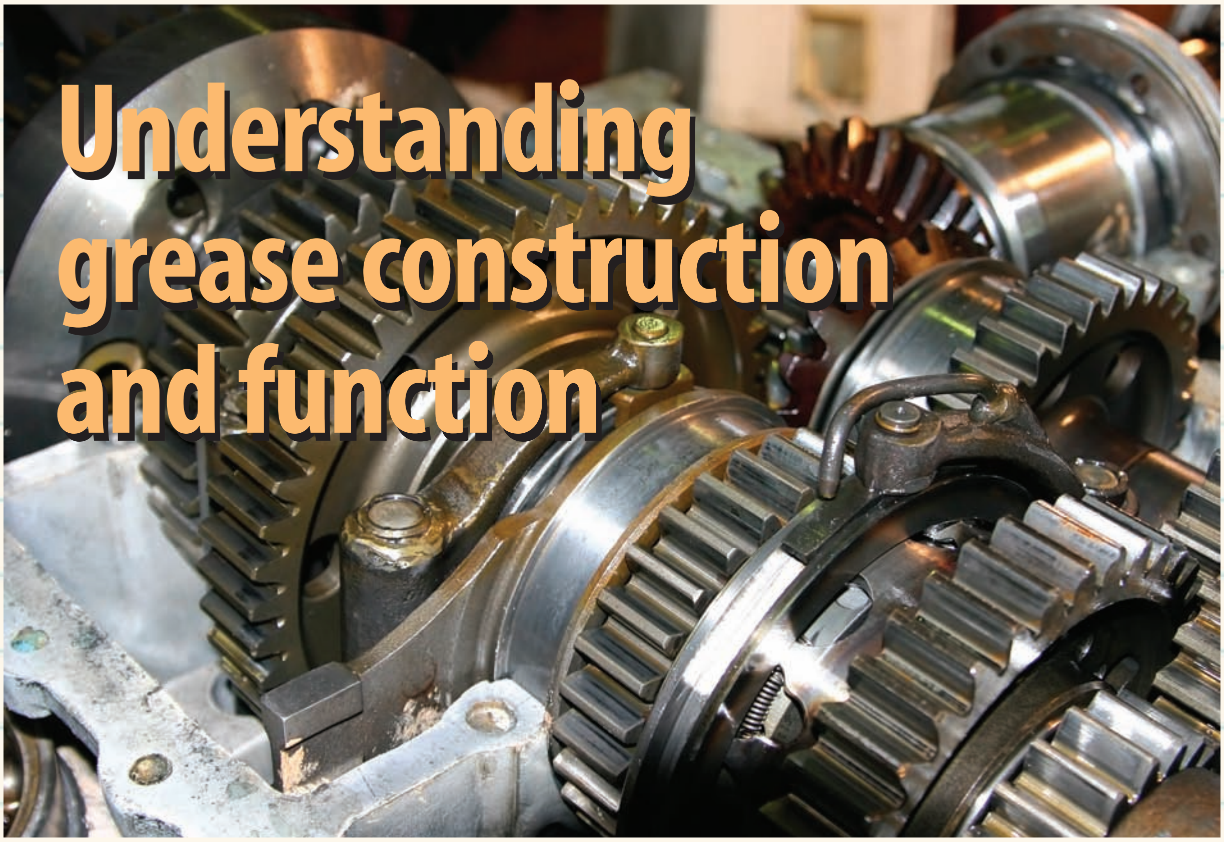

Understanding grease construction and function

A few key points about grease chemistry, ratings and the specific properties needed for your application.

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Article highlights:

- Benefits and drawbacks associated with grease usage.
- How grease stiffness ratings are formulated.
- Why chemistry affects key grease performance characteristics.
- Problems associated with mixing greases.

The March Best Practices Notebook introduced readers to important principles about the nature of lubricants and lubricant raw materials and how machines create an oil film when their surfaces begin to interact. This month we'll examine the somewhat specialized area of grease construction, performance attributes and issues of thickener compatibility. These topics are a prelude to lubricant selection, an issue we'll treat more in-depth in a future article.

Grease composition, function and performance

Sliding and rolling surface actions, coupled with differences in speed, load, component size and operating environment, all influence the type of oil film that is expected to form and the viscometric and additive properties that must be present within the oil to protect machine components.

The oil itself must provide the lift and surface protection functions in order for the grease lubricant to be effective. All of the base oil and additive type choices that were previously examined must be revisited when selecting the grease. In addition to those issues, the lubrication practitioner also must select from a variety of thickener systems, each with its own set of potential problems. Collectively, grease selection seems like a simple task, but if the reliability engineer wishes for the grease-lubricated components to have life cycles resembling oil-lubricated components, a significant number of variables must be fully considered.

Greases, as a category, fall into a classification of materials called non-Newtonian fluids. All fluids that experience a change in viscosity with change in shear stress are considered non-Newtonian. Mayonnaise, ketchup and hair gel are examples of common household non-Newtonian fluids. Greases that exhibit shear-induced thinning are referred to as thixotropic greases, and those that exhibit shear-induced thickening are referred to as rheopectic greases.

Both thixotropic and rheopectic responses are time dependent, meaning the thinning or thickening effect is more pronounced as the period of shear stress increases. In other words, thixotropic greases tend to liquefy as the elements in the machine squeeze, push and otherwise stress the fluid, and rheopectic greases tend to harden under the same types of mechanical force.

It would be ideal for the grease to "work thin" only at the point of immediate shear stress (motion of the lubricated component) and then instantaneously return to its original state the moment the stress force stops. If this condition existed, the grease would liquefy and function more like an oil at the point of motion and then reform and create an isolating seal when the motion stops. Unfortunately, the thinning and thickening effects tend to be permanent.

Greases perform their lubrication function over time by gradually releasing oil into the working areas of the contacting machine surfaces. This function has been compared to that of a sponge gradually releasing its liquid over a period of time. A more practical image would be of a concentration of millions of microscopic sponges held inside the machine, close to the working machine components, each one gradually releasing oil into the work zone. The greater the amount of sheer stress that the grease experiences (likened to squeezing the sponge) the faster the grease releases its hold of oil. Of course, once the sponge has released the oil, its usefulness is done. The oil and additive types contained within the sponge, and eventually released into the working areas of the machine, are selected based on the type of frictional conditions expected.

The permanent changes that the grease undergoes are accelerated by rising temperatures, increasing shear stress and mixture with other greases. For these reasons the reliability engineer must replenish the grease at an optimum time cycle, with an optimum volume to arrive at a replacement state that resembles the effectiveness of an oil bath.

Grease: Pros and cons

Previously we stated that machine lubricants have to perform six key functions:

1. Separate surfaces
2. Minimize friction
3. Cool the machine part
4. Clean the working area
5. Prevent corrosion
6. Provide a means of hydro-mechanical energy transfer.

With those being the stated objectives, there are benefits and drawbacks associated with using grease:

Grease Advantages	Grease Disadvantages
Reduced frequency of relubrication.	Loss of component cooling.
Decreased cost of machine design for lubrication.	Loss of component flushing.
Improved startup after a prolonged idle time.	Localized heat spikes/hot spots.
Improved sealing effectiveness (seal assistance).	Increased risk of lubricant incompatibility failure.
Reduced risk of process contamination.	Loss of contamination control functions (filtration).
More effective use of solid film additives.	Increased risk of lubricant oxidative failure.
Improved protection in high load/low speed machines.	Machine component speed limits vs. Oil.
	Increased risk of new lubricant contamination.
	Storage stability limitations.
	Increased risk of product variability/batch variability.
	Risk from relubrication practice: volume control.
	Risk from relubrication practice: frequency control.
	Risk from relubrication practice: viscosity selection.
	Risk from relubrication practice: application failure.

While it may be somewhat easier to identify potential drawbacks for the use of grease vs. oil,

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there clearly are advantages that make the use of grease compelling.

Grease construction[1]

The word grease is derived from the Latin word *crassus*, meaning fat. Early examples of systematic lubrication with animal fats date back to circa 1,400 BC, with efforts to reduce friction on wheel axels. From these very early roots, efforts to reduce friction were dependent on relatively abundant animal and vegetable-based oils. Colonel William Drake and his well-publicized oil well created a new way to supply an arguably superior oil product, which accelerated the move toward the use of mineral oil and hastened the birth of the petroleum age.

Mineral oil, as it turns out, is a pretty good raw material for lubricating surfaces. Taking the lead from the (hand, hair, laundry) type soap manufacturing industry, which has been robust since the early days of the period of the enlightenment, lubricant manufacturers adopted a soap manufacturing technique called saponification to produce the basis for building stable, useful petroleum greases. Saponification is the chemical reaction that produces soap, which becomes the grease thickener.

High school chemistry teaches that a mixture of an acid and a base produces a salt and water. If the acid happens to be an organic or fatty acid, then the product called is soap. Saponification occurs following the mixing of a fatty acid with an alkali component. The early fatty acids were produced by cooking animal and vegetable fats with water to separate glycerin and the inherent fatty acid. The early alkali component for soap manufacture was derived from soda ash, which comes from the alkali remains of burned vegetable matter.

Owing to the benefit of many early chemical industry developments, namely large-volume production of organic acids (Stearic acid – $C_{17}H_{35}COOH$ and Benzoic acid – C_6H_5COOH are both common organic fatty acids used in grease manufacture) and metallic hydroxides (lithium, aluminum, calcium, sodium and barium hydroxides), grease manufacturers learned to create specialized soaps into which mineral oils and additives were introduced to deliver highly specialized product functions.

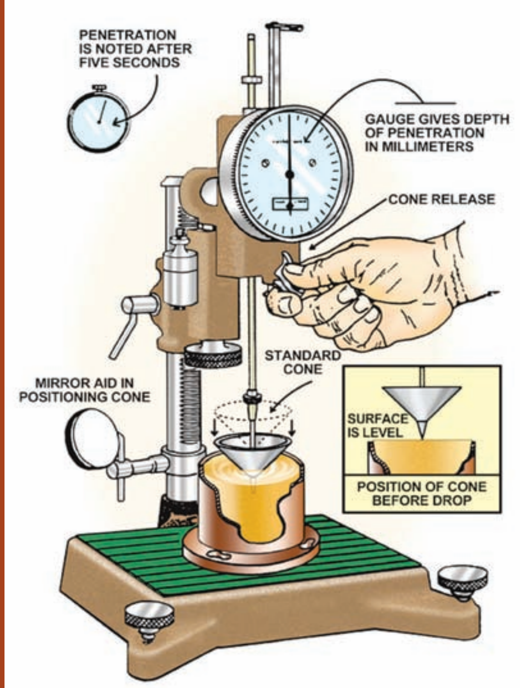
In the manufacturing process the raw materials for forming the soap, and some portion of the lubricating oil itself, are combined in a mixing vessel and blended/agitated to initiate the chemical reaction between the selected metallic thickener and fatty acid. The types and volumes of the materials used have a dramatic impact on the characteristics of the finished products.

Simple soap greases (primarily lithium, aluminum and calcium) are created if only one—a long chain—fatty acid is used during the soap formation process. If the supplier wishes to prepare a product to deliver better temperature resistance, then he will add another—a short chain—fatty acid in an additional step. Complex soap greases (lithium complex, aluminum complex, barium complex and calcium sulfonate complex) are known for superior temperature resistance vs. their simple soap counterparts.

Once the soap has been formed (using only a portion of the required lubricating oil) the balance of the lubricating oil is added, along with the remaining additives that are required to fortify the product for optimum results. The grease is cooled, milled to assure that the thickener is uniformly distributed through the other raw materials, and a sample is removed for stiffness testing.

The grease stiffness rating is the primary differentiating property that people use in selecting a grease. Grease stiffness is the characteristic that enables the grease to either move freely or sit still once placed into service. The higher the stiffness rating the thicker the grease body. The National Lubricating Grease Institute (NLGI) has devised a nine-point scale that is used in conjunction with ASTM D217 to grade grease stiffness. This method provides the user with a stiffness rating ranging between 000 and 6.

Figure 1. Grease penetration and consistency



(Source: *The Lubrication Engineers Manual, Third Edition*, (2007), The Association for Iron and Steel Technology, Warrendale, Pa., p. 92)

In the testing process, the sample of grease is cooled to 77 F, placed in a cup and smoothed over and, as shown in Figure 1, a pointed cone is placed on the surface of the grease. The operator releases a fastener and allows the cup to sink into the grease cup. Depending on the stiffness of the finished product, the cup may settle significantly or only slightly. Once the cup comes to rest, the operator measures the degree of drop based on the dial attached to the top of the rod supporting the cone. Figure 2 represents the profiles established by NLGI that dictate the grade or number of the finished product.

Figure 2. NLGI grease consistency values

NLGI Grades	Consistency Similar To	Worked Penetration 60 Strokes @ 25° C
000	Thick Cream	445 – 475
00	Tomato Sauce	400 – 430
0	Mustard	355 – 385
1		310 - 340
2	Tomato Paste	265 - 295
3		220 - 250
4	Soft Cheese	175 - 205
5	Hard Cheese	130 - 160
6	Block of Wax	85 - 115

The thickness number or NLGI grade of the grease only has implications relative to its requirement to either flow or not flow once applied to the mechanical structure requiring lubrication. With the exception of calcium sulfonate complex thickeners, the thickeners do not provide surface protection in addition to that provided by the base oil and additives. Having a grease rated as an NLGI No. 2 does not make it inherently superior or inferior to an NLGI No. 1 grease.

Each soap type imparts different performance properties worth noting. Reputable manufacturers will work vigorously to overcome weaknesses and enhance strengths of their respective products relative to the selected application types.

Key differences include: (*See micrograph pictures*).

- Aluminum and aluminum complex greases are known to have strong high-temperature performance characteristics, including high

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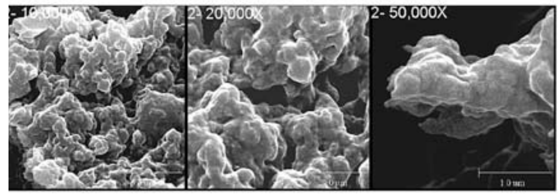
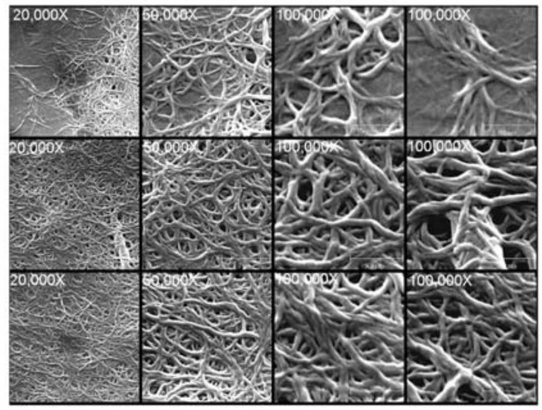
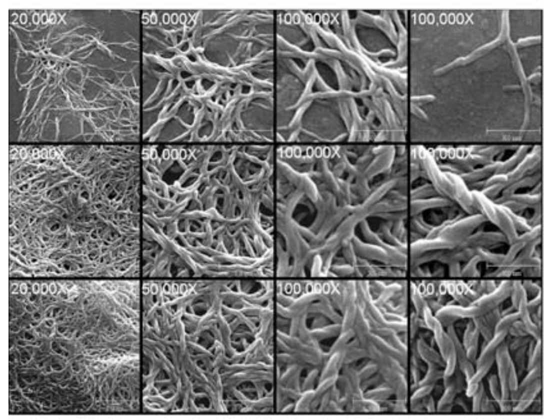


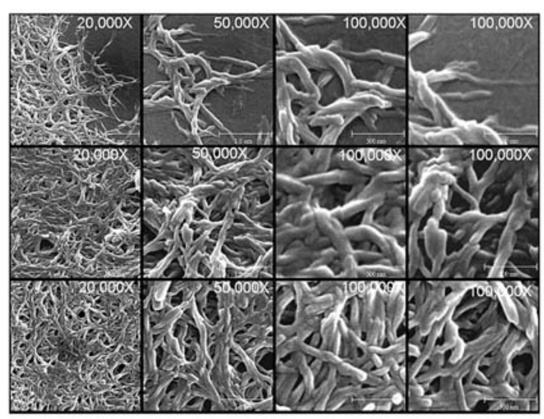
Micrograph (A): Aluminum Complex Greases Using STRATCO® Contactor™ Reactor



Micrograph (B): Calcium Greases Using STRATCO® Contactor™ Reactor



Micrograph (C): Lithium Greases Using STRATCO® Contactor™ Reactor



Micrograph (D): Lithium Complex Greases Using STRATCO® Contactor™ Reactor

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dropping points and very good oxidation-resistance. Aluminum-based greases also tend to perform well in high-wash applications, resisting the force of process waters and housekeeping wash hoses. These greases tend to be stringy, and this characteristic increases with rising sustained application temperature. These greases have been known to stiffen with extended use.

- Calcium, calcium complex, calcium sulfonate complex greases are best known for their excellent wash- and water-resistance properties and can be fortified to also provide strong corrosion-resistance properties. The complex and sulfonate complex forms are respected for high load-carrying capabilities and have temperature limits on par with other complex soaps. Calcium (hydrous and anhydrous) are best used in low to moderate temperature applications and have acceptable stability at moderate temperatures.

- Lithium and lithium complex greases are very widely used. These have strong properties in a variety of categories. These greases have excellent long-term work stability, strong high-temperature characteristics and have acceptable wash- and corrosion- resistance capabilities. With additive enhancement, the wash- and corrosion-resistance can be improved. These also have good low temperature shear performance, making them suitable for extremely low temperature applications. The generally well-rounded performance of these greases has made them the product of choice for general purpose grease relubrication in industrial and manufacturing environments.

> *Aluminum and aluminum complex greases are known to have strong high temperature performance characteristics, including high dropping points and very good oxidation-resistance.*

There is another category of grease thickeners, referred to generically as non-soap thickeners. These thickeners are made with a variety of products and processes, and deliver a wide array of performance results. The clay-based (bentonite) products and polyurea products represent the largest market volumes of non-metallic thickeners.

There are appreciable differences in the manufacturing practices for non-soap greases. Bentonite products are created by direct addition of the thickener to the base and additive mixture. These products require significant milling to assure uniformity. Polyurea thickeners are a type of polymer formed by a reaction between amines and isocyanates, which occurs during the grease formation process. Some of the common raw material options are considered to be hazardous, requiring careful environmental and health precautions for their manufacture.

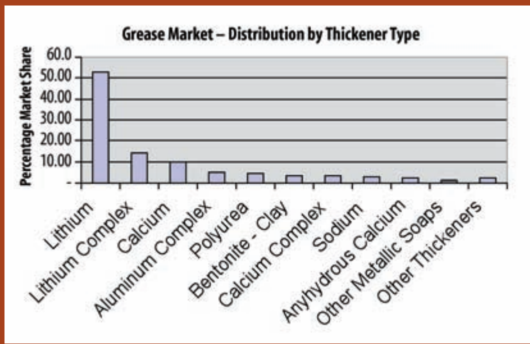
Common performance criteria for these non-soap greases include:

- Polyurea greases are preferred for use in ball bearing applications, giving rise to their broad-based acceptance in electric motor applications. Polyurea greases contain little to no heavy metals and have favorable high temperature performance. Together these two traits provide very good oxidation-resistance. Polyureas tend to have fair work stability, wash- and corrosion-resistance. Some polyureas have a low level of compatibility with other soap and non-soap greases, including other polyureas. Nonetheless, there are individual products being manufactured that demonstrate strengths in all of these categories, including the important issue of compatibility.

- Bentonite greases were the original non-melting grease. Bentonite is a type of clay. The base oils tend to evaporate before the clay material becomes hot enough to melt. This is both a strength and weakness. When used for extended periods of time at elevated temperatures, bentonite grease residues may cause a filling of the housing that can make long-term relubrication difficult. Bentonite greases are incompatible with most other grease types as well.

Figure 3 provides a breakdown of the general market distribution of several greases by thickener type.[2]

Figure 3. General market distribution of several greases by thickener type



In all grease products, the oil and the additives have the primary roles of lifting, separating and protecting surfaces, and the soap has the primary role of holding the oil in reserve until it is needed by the machine components. The March Best Practices Notebook suggested that lubricating oils can be constructed with a wide variety of additive compounds and base oil types and that some of those raw materials may well compete with one another. It was further suggested, since the lubrication practitioner was not routinely privy to the ingredients of any of the given products in use, that it would be best to avoid mixing lubricant products. That statement should be strongly reiterated, as it also pertains to the materials used as metallic thickeners to form the grease products.

Many studies have been conducted over the years that provide similar enough results that one can take away from the discussion of grease compatibility a simple rule: D*o not mix greases*! Mixtures of greases may fail to perform vs. either of the non-mixed products in a variety of ways, including:

Shear stability	Increase or decrease in the firmness of the grease mixture.
Dropping point	Decrease in the mixture's temperature stability.
Oxidation-resistance	Loss oxidation stability, increase in oxidation byproducts.
Wear-resistance	Loss of AW and EP additive performance.
Rate of oil dissociation (bleed)	Premature loss of oil reservoir leading to increased hardening.
Wash-resistance	Loss of ability to withstand passive or direct wash action of process solutions.

Not withstanding the changes that may occur with incompatibilities with base oils and additives, practitioners could expect obvious and prompt change in the greases stiffness (NLGI rating) and loss of temperature resistance, with the other changes occurring more gradually.

It is possible to know all of the ramifications that may occur when two or more greases are mixed, but not without a fair degree of testing and analysis. Unless one is going to expend the financial resources and effort to effectively study the

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degree of compatibility between different types of greases, one should avoid mixing if at all possible.

Figure 4 provides a useful general reference on the issue of thickener compatibility that the practitioner may use.[3]

Figure 4. Grease compatibility chart

	Aluminum Complex	Barium	Bentonite Clay	Calcium	Calcium 12 hydroxy	Calcium Complex	Calcium Sulfonate	Lithium	Lithium 12 Hydroxy	Lithium Complex	Polyurea	Sodium
Aluminum Complex	C	I	I	I	C	I	B	I	I	C	I	I
Barium	I	C	I	I	C	I	B	I	I	I	I	I
Bentonite Clay	I	I	C	C	C	I	B	I	I	I	I	I
Calcium	I	I	C	C	C	B	I	C	B	B	I	I
Calcium 12-hydroxy	C	C	C	C	C	B	NA	C	C	C	I	I
Calcium Complex	I	I	I	B	B	C	C	I	I	C	B	I
Calcium Sulfonate	B	B	B	I	NA	C	C	C	C	C	B	I
Lithium	I	I	I	C	C	I	C	C	C	C	I	B
Lithium 12-Hydroxy	I	I	I	B	C	I	C	C	C	C	I	I
Lithium Complex	C	I	I	B	C	C	C	C	C	C	I	B
Polyurea	I	I	I	I	I	B	B	I	I	I	C	I
Sodium	I	I	I	I	I	I	I	B	I	B	I	C
	C = Usually compatible. B = Borderline compatibility (probably incompatible). I = Incompatible NA = No information on compatibility.											

Summary

Grease manufacturing is a highly complex and detailed process. There are many different types of materials that may be used, each of which has some impact on the grease final performance characteristics. The two broad categories of greases include soap-thickened or non-soap thickened greases. While the thickener type does clearly have an influence on the long-term behavior of the grease, the majority of the surface protection work is provided by the oil and the additive choices. The NLGI grease stiffness rating system provides grease manufacturers with a clear mechanism for grading grease stiffness characteristics. **TLT**

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1. NLGI *Lubricating Grease Guide, Fourth Edition*, (1996), National Lubricating Grease Institute, Kansas City, Mo., pp. 1.09-1.12.

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3. Web reference: **http://www.finalube.com/reference_material/grease_compatibility_chart.htm**.