

3,424,678

LUBRICANT CONTAINING ALKALINE EARTH METAL MIXED SALT THICKENERS AND COLLOIDAL ASBESTOS

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7 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to lubricating oils, including mineral oil, polyphenyl oils, and polysilicone oils, etc., containing alkaline earth metal mixed salts of 5 to 50 molar proportions of C₂ to C₆ fatty acid per molar proportion of C₇ to C₃₀ fatty acids, and containing colloidal asbestos having particle outer diameters of 1 to 80 millimicrons and particle lengths of 2,000 to 30,000 millimicrons as an improving agent.

DESCRIPTION OF THE INVENTION

Lubricants, containing alkaline earth metal salts of mixtures of C₂ to C₆ fatty acid and C₇ to C₃₀ fatty acid, have found widespread commercial use. In general, these mixed salts, particularly those containing calcium acetate as one of the mixed salts, reduce wear and impart extreme pressure properties to the lubricant. Fluid lubricants containing calcium salts of acetic acid and C₇ to C₁₂ acids, e.g. coconut oil acids, are in widespread use for lubrication of the upper cylinders of marine diesel lubricants. Solid lubricants, e.g. greases, containing calcium salts of acetic acid and C₁₃ to C₃₀ fatty acid, are in widespread use as industrial greases and for automotive chassis greases. It has now been found, generally speaking, that a small amount of colloidal asbestos in these mixed salt lubricants will materially improve the life of the lubricant during high temperature use, will reduce the total amount of thickeners required to thicken the oil to a desired consistency, will increase water resistance and will prevent hardening and drying out of the grease at elevated temperatures.

The use of prior natural asbestos as an ingredient of lubricating compositions is old in the art, and a number of various grease formulations are taught in the book "Lubricating Grease" by C. J. Boner, 2nd edition, pages 687 et seq. These known greases utilized conventional asbestos or asbestos floats, which are relatively long fibered asbestos agglomerates. However, this long fibered asbestos was used in conjunction with other thickening agents such as soaps, since the long fibered asbestos will not form a thickened homogeneous grease gel by itself, but rather relies upon other ingredients to form the grease or gel-like structure. The asbestos of the present invention differs from the aforesaid long fibered conventional asbestos in that the asbestos fibers are separate and distinct, occurring in a small colloidal size, having a large surface area, and can be dispersed in oil to form a gel by themselves, and without settling out from the oil. This colloidal asbestos is chrysotile having the chemical formulation Mg₆(OH)₈Si₃O₁₀. The usual mode of occurrence of chrysotile is a "cross-fiber" configuration in which filaments of chrysotile (i.e. bundles of fibers) are closely packed together and set at right angles to the walls of cracks and fissures that extend through the host rock of the ore body. However, in 1959, an unusual deposit of chrysotile asbestos, with properties and a mode of occurrence different from the previously known cross-fiber material, was discovered in central California. The ore of

this new deposit, instead of occurring in veins, occurs in randomly-oriented, matte-like flakes and agglomerates of visible asbestos filaments, which in turn are made up of many thousands of extremely small tubular fibers. The lengths of these small fibers vary from a few millimicrons to thousandths of millimicrons, generally, 2,000 to 30,000 millimicrons, while the diameters of the fibers vary much less and are usually in the range of 1 to 80, e.g. 10 to 30 millimicrons. A typical colloidal asbestos that was used in the working examples of the invention had the following characteristics.

Properties of colloidal asbestos fibers:

- Brightness (GE) ---- 74-76.
- Refractive index ---- 1.55.
- Dispersion in water .. Fully/pH range 4-6.
- Surface area ----- 47-50 sq. meters/gram.
- Oil absorption ----- 14-16 cc./10 grams of fibers.
- Water retention ----- 42 grams/20 grams of fibers.
- Dry bulk density ---- 2-2.5 lbs./cu. ft.
- Fiber dimension:
- O.D. ----- 25.0 millimicrons.
- I.D. ----- 6.0 millimicrons.
- Length ----- 2,500-25,000 millimicrons.

Generally, the lubricants of the invention will comprise a major amount of either a mineral or synthetic lubricating oil, containing about 2 to 45 wt. percent, usually 10 to 35 wt. percent, of mixed salt thickener, and about 1.0 to 30.0, preferably 2 to 15, wt. percent of colloidal asbestos, all of said weight percents being based on the total weight of the lubricant. The mixed salt thickeners are usually formed by co-neutralization in oil, by alkaline earth metal base, of mixtures of C₂ to C₆, i.e. low molecular weight, fatty acid, and C₇ to C₃₀ higher molecular weight fatty acids, which can be considered as two groups, namely C₇ to C₁₂ intermediate molecular weight fatty acid, and C₁₃ to C₃₀ high molecular weight fatty acid. Usually 4 to 50, preferably 4 to 35, molar proportions of C₂ to C₆ fatty acid is used per molar proportion of higher fatty acid.

The low molecular weight acids include acetic, propionic, n-butyric, etc. Acetic acid or its anhydride is preferred.

Intermediate molecular weight fatty acids include those aliphatic, saturated, unsubstituted, monocarboxylic acids containing 7 to 12 carbon atoms per molecule, e.g. capric, lauric, caprylic, nonanoic acid, etc.

The high molecular weight fatty acids useful for forming the mixed-salt thickeners include naturally-occurring or synthetic, hydroxy substituted and unsubstituted, saturated and unsaturated, mixed or unmixed fatty acids having about 13 to 30, preferably 16 to 22, carbon atoms per molecule. Examples of such acids include stearic, hydroxy stearic, such as 12-hydroxy stearic, dihydroxy stearic, polyhydroxy stearic and other saturated hydroxy fatty acids, arachidic, oleic, ricinoleic, hydrogenated fish oil, tallow acids, etc.

Metal bases which are frequently used to neutralize the above acids are the hydroxides, oxides or carbonates of alkaline earth metals, e.g. calcium, magnesium, strontium and barium.

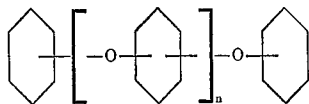
The lubricating oil used in the compositions of the invention may be either a mineral lubricating oil or a synthetic lubricating oil. Synthetic lubricating oils which may be used include polyphenyl ether oils, polysilicone oils, esters of dibasic acids (e.g. di-2-ethylhexyl sebacate), esters of glycols (e.g. C₁₃ oxo acid diester of tetraethylene glycol), complex esters (e.g. the complex ester formed by reacting one mole of sebacic acid with two moles of tetra-ethylene glycol and two moles of 2-ethylhexanoic acid), halo-carbon oils, alkyl silicates, sulfite

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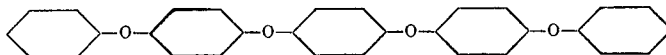
esters, mercaptals, formals, polyglycol type synthetic oils, etc. or mixtures of any of the above in any proportions.

Preferred synthetic lubricating oils are the polyphenyl oils and the polysilicone oils, when the lubricant is designed for high temperature use, since they are particularly stable at high temperatures.

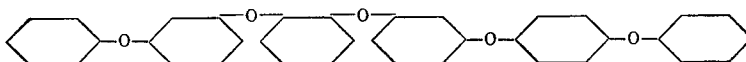
The polyphenyl ether oils of the invention are those normally liquid (at 77° F.) ethers represented by the general formula:



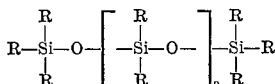
where n is about 2 to 6. The oxygen atoms attached to the hydrocarbon rings intermediate the terminal phenyl groups, can be in an ortho, meta, or para position relative to each other. Isomeric mixtures of polyphenyl ethers within the above formula are also included in the invention, as well as mixtures of polyphenyl ether molecules having different values for n . An oil of the above general formula wherein n was 3, obtained from Monsanto Chemical Co. under the designation "High Temperature Functional Fluid and Lubricant OS-124," was used in the working examples of this invention. Some other specific examples of these polyphenyl ethers include the following:



and



The silicone polymers which can be used are silicon oils having viscosities of about 1 to 500 centistokes at 25° C. These oils have the general formula:



wherein R represents halogen substituted (e.g. chlorine) or unsubstituted hydrocarbon radicals including alkyl, aryl, haloaryl, alkylaryl, arylalkyl and cycloalkyl radicals containing between about 1 to 8 carbon atoms per radical, and n is an integer whose average value depends upon the viscosity of the oil. Specific examples of such oils include phenyl-methylsilicone, dimethylsilicone and chlorophenylmethylsilicone. Silicone oils are well known in the art and are commercially available under trade names such as DC (Dow Corning) F-258 Silicone Fluid, DC-200 Silicone Fluids of 1 to 50 cs., DC F-60 Silicone Fluid, DC-510 Silicone Fluid, DC-550 Silicone Fluid, DC-555 Silicone Fluid, DC-710 Silicone Fluid, QF-6-7012 Silicone Fluid, QF-6-7024 Silicone Fluid, etc.

Various other additives may also be added to the lubricating composition in amounts of 0.1 to 10.0 wt. percent each. Such additives include lubricating oil sludge detergents and dispersants; oxidation inhibitors such as phenyl-alpha-naphthylamine; corrosion inhibitors such as sorbitan monooleate and sodium nitrite; dyes; other grease thickeners; and the like.

The aforementioned lubricating oil sludge dispersants or detergents are used in some mixed-salt lubricants to help improve the stability and improve filterability of semi-fluid mixed salt lubricants, e.g. see U.S. Patent 3,125,521 as an example.

One type of these sludge dispersants is phosphosulfurized polyolefin prepared by reacting a polymer of a C_2 to C_6 monoolefin-1 with P_2S_5 , for 0.5 to 15 hours at 150° to 600° F., to form a material believed to be a dithiophosphoric acid. P_2S_5 treated polyisobutylene of 40 to 250 carbon atoms is a particularly preferred dis-

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persant of this type. Preparation of these phosphosulfurized polyolefins is well known, for example, see U.S. Patent 2,875,188. The phosphosulfurized polyolefin can be used per se, or it can be first hydrolyzed wherein it is treated with steam to increase its acidity, or it can be used in the form of its metal salts, e.g. it can be co-neutralized with the fatty acids used to make the mixed salt lubricant.

Other types of sludge dispersants are imides and amides formed by reaction of a mole of polyethyleneamine containing 2 to 12 nitrogen atoms per molecule, e.g. tetraethylenepentamine (5 nitrogen atoms), with one to four moles of a long chain mono- or dicarboxylic acid or anhydride, containing a total of 50 to 250 carbon atoms, such as polyisobutenylsuccinic anhydride, or polyisobutenyl monocarboxylic acid having the structure



where R is the polyisobutenyl group. Examples of such dispersants are described in U.S. Patent 3,172,892 and Belgian Patent 658,236.

Other types of dispersants include said polyisobutenylsuccinic anhydride per se, said polyisobutenyl monocarboxylic acid per se, and metal salts, e.g. alkaline earth metal salts, of these materials which can be formed in situ during neutralization of the fatty acids with the alkaline earth metal base as the grease is made.

The lubricants of the invention can be formed in a number of different ways. The most convenient way is to neutralize the fatty acid with metal base in oil, with the asbestos either present during the neutralization or added later. Usually, the resulting composition will then be heated to about 225° F. to 600° F., preferably 325° F. to 500° F., to dehydrate the composition of water of reaction. In general, particularly when using acetic acid or its anhydride, the higher temperature of 400° F. to 600° F. will result in the formation of a salt material having greater thickening effect and better load and E.P. properties than lower dehydration temperatures, e.g. 300° F. to 350° F., although lower dehydration temperatures of about 320° F. can be achieved in the more common steam heated grease kettles. The final grease can be milled or homogenized. This will tend to break down some of the asbestos fibers, particularly the longer ones, but has no apparent detrimental effect on the asbestos.

The invention will be further understood by the following examples, which include preferred embodiments of the invention and wherein all parts are by weight.

Example I.—Part A

55.6 parts of polyphenyl ether (Monsanto OS 124), 14.6 parts of hydrated lime, 3.6 parts of polyisobutylene succinic anhydride, and 3.44 parts of tallow fatty acid were added to a steam jacketed grease kettle and mixed for 30 minutes. Then, 22.0 parts of glacial acetic acid were slowly added to the kettle over a six hour period while maintaining the temperature of the kettle contents below about 200° F. After all the acetic acid had been added, the temperature of the reaction mixture was then increased to 320° F., which temperature was held for about 30 minutes in order to dehydrate the mixture of the water of reaction. The product was then cooled rapidly over a period of about 30 minutes to 250° F., and then one part of phenyl-alpha-naphthylamine was added as an oxidation inhibitor. The grease was then further cooled to 100° F. and then homogenized by passage through a

Morehouse mill having a clearance of .003". The resulting grease was slightly on the alkaline side so that all the fatty acid, as well as the polyisobutylene succinic anhydride is neutralized, i.e. the succinic anhydride is converted to the calcium salt.

The polyisobutenyl succinic anhydride had a total molecular weight of about 1100.

The high molecular weight fatty acid that was used is tallow fatty acid having a Saponification No. of about 195, an Iodine No. (Wijs) of about 55 and consisted of

silicone consisted of about 60 wt. percent phenyl groups and about 40 wt. percent methyl groups. The polysilicone had viscosities of about 298 SUS at 100° F. and about 104 SUS at 210° F.

The slightly alkaline grease products of Examples I through III, their formulations and properties, are summarized in the following table, along with similar data on Comparison Grease A which was made according to the method of Example I, Part A, but with different amounts of ingredients, and which contained no asbestos.

TABLE I

Composition (wt. percent)	Comparison grease A	EXAMPLES		
		I	II	III
Glacial acetic acid.....	11.00	11.00	11.08	11.08
Tallow fatty acid.....	1.72	1.72	1.72	1.72
Polyisobutylene succinic anhydride.....	1.18	1.18	1.18	1.18
Hydrated lime.....	7.30	7.30	7.30	7.30
Colloidal asbestos.....	5.00	5.00	5.00	5.00
Phenyl-alpha-naphthylamine.....	1.00	1.00	1.00	1.00
Polyphenyl ether oil.....	77.80	72.80	72.80	72.80
Phenyl-methyl polysilicone oil.....				72.80
Mole ratio acetic/higher fatty acid.....	29/1	29/1	29/1	29/1
Properties:				
Appearance.....		Excellent smooth grease		
Dropping point, ° F.....	500+	500+	500+	500+
ASTM penetration, 77° F:				
Unworked.....	285	285	290	290
Worked 60 strokes.....	290	275	298	300
Worked 10,000 strokes.....	300	290	285	305
Lubrication life, NLGI-ABEC test 10,000 r.p.m., 400° F., hours.....	619	1,377	1,618	250
Aluminum block test at 450° F.....	(1)	(2)	(2)	(3)

¹ Dried and gummy after 10 hrs.

² Good after 150 hrs.

³ Dried to powdery product in 48 hrs.

about 55 wt. percent of C₁₆ acid and about 45 wt. percent C₁₈ acid.

Example I.—Part B

In a separate grease kettle, an asbestos mixture was prepared by adding to the kettle 89 parts of polyphenyl ether (same as in Part A); 10 parts of colloidal asbestos previously described, and one part of phenyl-alpha-naphthylamine (the phenyl-alpha-naphthylamine was predissolved at 130° F. in a small amount of the polyphenyl ether before adding to the kettle). The kettle contents were then thoroughly stirred.

Example I.—Part C

Equal parts of the products of Part A and Part B were combined in a grease kettle by simply mixing them together at room temperature, and then passing them on to a Morehouse mill where the resulting mixture was milled, to form a slightly alkaline grease.

Example II

72.8 parts of polyphenyl ether (Monsanto OS 124), 7.3 parts of hydrated lime, 1.18 parts of the polyisobutylene succinic anhydride, 1.72 parts of the tallow fatty acid, and 5.0 parts of the colloidal asbestos, were added to a steam jacketed grease kettle and mixed for 30 minutes. Then, 11.08 parts of glacial acetic acid were slowly added to the kettle over a 6-hour period while maintaining the temperature of the kettle contents below about 200° F. After all the acetic acid had been added, the temperature of the reaction mixture was then increased to 320° F., which temperature was held for about 30 minutes in order to dehydrate the mixture of the water of reaction. The product was then cooled rapidly over a period of about 30 minutes to 250° F., where one part of phenyl-alpha-naphthylamine was added. The grease was then further cooled to 100° F. and then passed through a Morehouse mill having a clearance of .003" to form the slightly alkaline finished lubricant.

Example III

This grease was prepared in the same manner as that of Example II except that a polysilicone oil, namely, phenyl-methyl polysilicone (F-6-7012), was used in place of the polyphenyl ether. The hydrocarbon radicals of the poly-

As seen by Table I, greases of Examples I to III, having high dropping points and a high degree of stability to mechanical working, were obtained using the colloidal asbestos. Specifically, the polyphenol ether greases of Examples I and II were outstanding in their high temperature properties and also their resistance to breakdown as shown by the Aluminum Block Test, as compared to Comparison Grease A without asbestos. This test is carried out by placing the test grease in ¼" grooves cut in the surface of an aluminum block and heating the block to 400° F. Thus, the greases of Examples I and II, after 150 hours at 400° F. in the Aluminum Block Test, showed no increase in hardness and retained their grease-like properties. In addition, the grease of Example I had a lubrication life of 1377 hours as compared to only 619 hours for the same grease (Comparison Grease A) without asbestos, thus demonstrating a significant improvement by use of the asbestos. In fact, the grease of Example II gave a lubrication life (NLGI-ABEC) of 1244 hours under a 100 pound thrust load at 400° F., and 258 hours under a 100 pound thrust load at 450° F. The polyphenyl greases of Examples I and II also demonstrate another advantage, in that similar grease without asbestos had to be prepared using a transfer technique involving an inert solvent as taught in U.S. Patent 3,198,734 in order to get the best dispersion, while the use of asbestos did not require this solvent technique to get the best grease structure obtainable with these ingredients.

Example IV.—Part A

3.5 parts of coconut fatty acid, 2.5 parts of 12-hydroxy stearic acid, 9.2 parts of hydrated lime, and 7.8 parts of a mineral lubricating oil having a viscosity of 55 SUS at 210° F., are mixed together in a grease kettle, following which 12 parts of glacial acetic acid are slowly added to the mixture, while keeping the temperature below about 200° F. The grease composition is then heated to about 320° F. for about one hour to remove water of reaction. The grease is then cooled to about 200° F. where one part of phenyl-alpha-naphthylamine is added as an antioxidant. The grease is then milled by passage through a Morehouse mill and then cooled to form the final grease product.

Example IV.—Part B

50 wt. percent of the grease prepared above was mixed with a 50 wt. percent dispersion consisting of 10 wt. percent of the colloidal asbestos dispersed in 90 wt. percent of said mineral lubricating oil.

The compositions prepared and their properties are summarized in the following Table II.

TABLE II

Formula (wt. percent)	Example IV	
	A	B
Acetic acid.....	12.0	6.0
Coconut fatty acid.....	3.5	1.75
Hydrated lime.....	9.2	4.60
Phenyl-alpha-naphthylamine.....	1.0	.50
12-hydroxy stearic acid.....	2.5	1.25
Colloidal asbestos.....		5.00
Mineral lubricating oil of 55 SUS at 210° F.....	71.8	80.90
Mole ratio acetic/higher fatty acid.....	6/1	6/1
Properties:	(1)	(2)
Appearance.....		
Dropping point, ° F.....	500+	500+
ASTM penetration 77° F./mm./10:		
Unworked.....	313	300
Worked 60 strokes.....	311	295
Worked 10,000 strokes.....	320	290
Lubrication life, NLGI-ABEC Test, 10,000 r.p.m. at—:		
250° F.....	2,000+	2,000+
300° F.....	40	250
350° F.....	30	280
Aluminum block test, 400° F., hrs. to become powdery.....	20	20

¹ Excellent. ² Homogeneous.

Table II shows that a mineral lubricating oil calcium mixed salt grease A can be significantly improved in its high temperature lubrication life at 300° F. and 350° F. by use of the asbestos as shown by grease B. Also, grease B shows that the amount of mixed salts present can be drastically reduced by the incorporation of a lesser amount of the asbestos, while maintaining a high dropping point and about the same degree of thickening power as indicated by the ASTM penetration. This represents an economic advantage since the cost of Grease B is thereby significantly less than Grease A as the cost of the asbestos is roughly about the same, or even less, than the mixed salt thickener on a weight basis.

Example V.—Part A

A grease concentrate was prepared by mixing together 0.72 part of tallow fatty acid (same as in Example I), 0.52 part of polyisobutylene succinic anhydride having a molecular weight of about 1100 (same as in Example I), 0.37 parts of an oil consisting of 70 wt. percent P₂S₅ treated polyisobutylene in about 30 wt. percent mineral lubricating oil, 2.98 parts of hydrated lime, and about 22.5 parts of mineral lubricating oil having a viscosity of 80 SUS at 210° F. 4.68 parts of glacial acetic acid was slowly added to the mixture while maintaining the reaction mixture below about 200° F. After the acetic acid addition, the composition was heated to about 320° F. to remove water of reaction, and 1 part of phenyl alpha naphthylamine was added as an antioxidant, and another 0.73 part of the P₂S₅ treated polyisobutylene was also added to facilitate filtration, after which the hot concentrate was filtered. Following this the concentrate was cut back by the addition of 67.45 parts of additional lubricating oil. The resulting filtered concentrate was homogenized by passage through a Morehouse mill to form the semi-fluid or fluid product which is substantially neutral and wherein the succinic anhydride and the first addition of the P₂S₅ treated polyisobutylene are neutralized with the lime. The second addition of P₂S₅ treated polyisobutylene is not neutralized since the neutralization process has already been completed and the material is slightly on the acid side when this second addition is made.

Example V.—Part B

50 parts of the above composition was mixed with 50 parts of a concentrate consisting of 5 wt. percent of the colloidal asbestos dissolved in 95 wt. percent of a mineral lubricating oil.

The P₂S₅ treated polyisobutylene was prepared by reacting polyisobutylene of about 800 molecular weight with about 15% P₂S₅, based on the weight of the polyisobutylene, at about 425° F. for about 8 hours under a nitrogen atmosphere.

The compositions prepared and their main properties are summarized in the following Table III.

TABLE III

Formulation (percent wt.)	A		B	
Acetic acid.....	4.68	2.34		
Tallow fatty acid.....	0.72	.36		
Polyisobutenyl succinic anhydride.....	0.52	.26		
P ₂ S ₅ treated polyisobutylene (30 wt. percent in oil)	1.10	.55		
Hydrated lime.....	2.98	1.46		
Phenyl alpha naphthylamine.....	0.25	.125		
Colloidal asbestos.....		2.5		
Mineral lubricating oil, 80 SUS at 210° F.....	89.95	92.405		
Properties:				
Vis./100.....	1,732	Solid		
Vis./210.....	100.4	Solid		
Lubrication life, hours 10,000 r.p.m. at—:				
250° F.....			1,500+	
300° F.....			600	
ASTM penetration, 77° F., mm./10:				
Unworked.....			300	
Worked 60 strokes.....			310	
4-Ball Wear Test, Scar diam. mm. (1,800 r.p.m., 75° F., 1 hr., 10 kg.).....	0.25	0.29		
Water solubility, (212° F.).....	(1)	(2)		

¹ Disintegrates.

² Untouched, remains solid.

As seen by Table III, Example V(B) shows that a small amount of the colloidal asbestos converts the fluid calcium acetate lubricant (Example V(A)) to a solid grease, which will not disintegrate in boiling water, while still having good antiwear properties. If desired, the addition of less asbestos to the composition of Example V(A), or of more oil to the composition of Example V(B) would give a semi-fluid lubricant.

What is claimed is:

1. A lubricating composition comprising a major amount of lubricating oil, about 2 to 45 wt. percent of alkaline earth metal mixed salts of C₂ to C₆ fatty acid and C₇ to C₃₀ fatty acid in a relative mole ratio of 4 to 50 molar proportions of said C₂ to C₆ fatty acid per molar proportion of said C₇ to C₃₀ fatty acid, and about 1 to 30 wt. percent of colloidal tubular asbestos having particle outer diameters of about 1 to 80 millimicrons and particle lengths of about 2,000 to 30,000 millimicrons.

2. A lubricant according to claim 1, wherein said C₇ to C₃₀ fatty acid is 12-hydroxy stearic acid.

3. A lubricating grease according to claim 1, wherein said alkaline earth metal is calcium, and said C₂ to C₆ fatty acid is acetic acid.

4. A lubricating grease according to claim 3, wherein said oil is mineral lubricating oil.

5. A lubricating grease according to claim 3, wherein said oil is a polyphenyl ether lubricating oil containing 4 to 7 ether linkages.

6. A lubricating grease according to claim 3, wherein said oil is a polysilicone lubricating oil.

7. A lubricating grease comprising a major amount of lubricating oil, about 10 to 35 wt. percent of calcium mixed salts of acetic acid and C₁₂ to C₃₀ fatty acid in a relative mole ratio of 4 to 35 molar proportions of said acetic acid per molar proportion of said C₁₂ to C₃₀ fatty acid, and about 2 to 15 wt. percent of colloidal tubular asbestos having particle outer diameters of about 1 to 80 millimicrons and particle lengths of about 2,000 to 30,000 millimicrons.

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