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(54) **Title**: METHOD AND APPARATUS FOR REDUCING WEAR OF SURFACES IN CONTACT WITH ONE ANOTHER

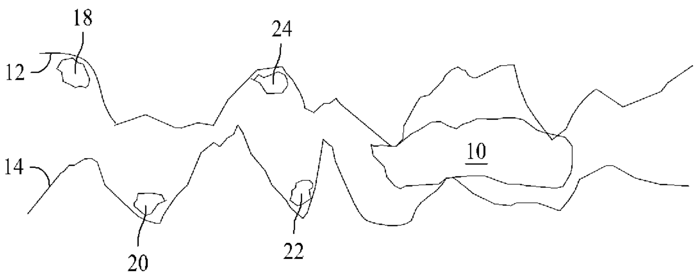

FIG. 1

(57) **Abstract**: A method for reducing wear between two surfaces in sliding contact with one another includes introducing nanoparticles between the two surfaces in an amount and having a composition that results in shear lines being generated within at least one agglomerated wear particle that is generated between the two surfaces as a result of the sliding contact, and subjecting the agglomerated wear particles to at least one load, using at least one of the two surfaces, such that the agglomerated wear particles disassemble along the shear lines into multiple smaller wear particles.

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METHOD AND APPARATUS FOR REDUCING WEAR OF SURFACES IN CONTACT WITH ONE ANOTHER

BACKGROUND

The field relates generally to machining and other fabrication and manufacturing processes, and more specifically, to methods and apparatus for reducing wear of surfaces in contact with relative motion with respect to one another, including, for example, sliding, rolling, and other forms of motion.

Many processes are known where friction from a first metal device engaging a second metal device produces heat, wear, deformation, and surface blemishes. Sometimes, the two devices may be different metals, one of the devices may not be a metal, or neither of the devices may be metal, such as ceramic. One simple example is the drilling of holes into a component using a bit. In many of these applications, the wear resulting from the sliding engagement between the two devices eventually results in reduced quality, increased heat generation and a corresponding reduction in process speed or reduced energy efficiency. Other detrimental results from the above described sliding engagement between two surfaces are also known. Types of wear include erosion, cavitation, rolling, sliding and rolling, and impact (large body, small particle, and liquid). Types of contact between surfaces can include sliding abrasion ("two body"), rolling abrasion ("three body") and scratching.

Reducing wear in such applications is desired since it allows a tool or a die to be used longer simply because it lasts longer. In physical terms, reducing wear translates into reducing the rate at which material from one of the devices is removed from its acting surface. In one practical example, reducing wear allows a drill bit to drill more holes before it needs to be replaced. The drill bit can be used longer because the surface quality, including for example a smoothness associated with the surface, is less adversely affected.

Current implementations within such processes do not necessarily reduce wear. Instead, such implementations attempt to reduce friction. Solutions for reducing friction include the adding of lubricants, such as oils, greases, and solid lubricants, for example, molybdenum disulfide (MoS_2), to processes; and dry lubricants such as coatings and powders. Other solutions include custom coatings applied to the surface where engagement is expected to occur.

Various custom coatings can be used to protect surfaces, such as coating the cutting surfaces of drill bits. However, once the drill bit is worn out (in some applications this can occur in as few as three holes, at $75/bit, for some composite material drilling processes), it must be reground. Regrinding removes the coating so the bit must also go through the coating processes again before it can once again be utilized in the process.

While the accumulation and agglomeration of wear particles at the sliding interface and their adverse effects on friction and wear are known, the means for breaking down wear agglomerates has not been well considered. One beneficial method is to develop a method or system to reduce particle size that can accumulate between sliding surfaces, especially in applications with substantial forces between the surfaces. Particle size reduction can result in greater direct contact between the surfaces. Such a method and system would improve efficiency and cost effectiveness of many industrial applications such as drilling and grinding.

BRIEF DESCRIPTION

In one aspect, a method for reducing wear between two surfaces in sliding contact with one another is provided. The method includes introducing nanoparticles between the two surfaces, in a quantity and composition that results in shear lines being generated within at least one agglomerated wear particle. These agglomerated wear particles are generated between the two surfaces as a result of the sliding contact between the surfaces. By subjecting the agglomerated wear particles to at least one load, using at least one of the two surfaces, such that the agglomerated wear particles disassemble along the shear lines into multiple smaller wear particles, allowing for protected contact between the two surfaces.

In another aspect, a method for reducing wear between two surfaces in sliding contact with one another is provided. The method includes using nanoparticles to destabilize agglomerated wear particles that build up between the two surfaces as a result of the sliding contact, and causing the destabilized, agglomerated wear particles to break down into smaller pieces, allowing for protected contact between the two surfaces.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments, of the present invention or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of an agglomerated wear particle between two surfaces that are intended to be in sliding contact with one another.

Figure 2 is a depiction of an agglomerated wear particle that is destabilized through introduction of shear lines therethrough.

Figure 3 illustrates the agglomerated wear particle of Figure 2 broken up into multiple, smaller wear particles.

Figure 4 is a graph that illustrates reduction in wear as a function of nanoparticle concentration of hexagonal boron nitride, molybdenum disulfide, or tungsten disulfide nanoparticles being added to a lubricant in a sliding contact process between two surfaces.

Figure 5 is a graph that illustrates different rates in the reduction in wear when hexagonal boron nitride, molybdenum disulfide, or tungsten disulfide nanoparticles are added to a lubricant in a sliding contact process between two steel surfaces.

Figure 6 is a graph that illustrates different rates in the reduction in wear of 440C steel balls when different particle concentrations of hexagonal boron nitride, molybdenum disulfide, or tungsten disulfide nanoparticles are added to a lubricant in a process where the steel balls are sliding against steel sheets.

DETAILED DESCRIPTION

The embodiments described herein relate to methods and compositions for reducing mass loss of either or of both surfaces when those two surfaces are in sliding contact with one another. Generally, the surfaces are metal, such as a drill bit and a component on which the drill bit is operating. However, the embodiments are certainly applicable in applications where one or both of the surfaces are not metal. The reduction in the loss of mass occurs through the destabilization of agglomerated wear particles that are generated during the sliding contact, or rubbing, between the two items or surfaces. In other embodiments, the agglomerated wear particles may be referred to as a “solid film” which may have a relatively higher aspect ratio that is different from substantially spherical.

Figure 1 is a prior art illustration of an agglomerated wear particle 10 between two surfaces 12 and 14 that are in sliding contact with one another. Figure 1 is a microscopic view which illustrates that surfaces 12 and 14 are imperfect, exhibiting a series of peaks and valleys. However, surfaces 12 and 14 are illustrative of typical surfaces which, while possibly appearing smooth to the naked eye and possibly feeling smooth to the touch, actually can have fairly large asperities at low magnification.

As is known in the art, worn debris removed from one or both rubbing surfaces 12 and 14 tend to aggregate under the contact pressure to create the agglomerated wear particle 10, which can be abrasive especially to the softer of the two surfaces 12 and 14. This agglomerated wear particle 10 is less effective as an abrasive as long as it remains smaller than some characteristic dimension of the surface finish. As wear particle 10 increases in size, the interaction between the two surfaces 12 and 14 is diminished due to the buildup in size of wear particle 10. More specifically, surfaces 12 and 14 stop interacting directly with one another because the wear particle 10, and other particles like wear particle 10, increase in size. The wear particles, such as wear particle 10, are abrasive because they are work hardened as a result of plastic deformation and affect both of the opposing surfaces 12 and 14. Essentially, wear particle 10 is operating on both surfaces 12 and 14. In the drilling example, when the wear particle 10 is of sufficient size, it is performing the material removal, based on a pressure applied by the bit to the wear particle 10, instead of the bit acting directly on a surface. However, this interaction is not nearly as efficient as a direct interaction between the surfaces 12 and 14. Further, as surface 12 represents a cutting tool designed to operate on surface 14, the abrasion received on surface 12 from wear particle 10 acts to reduce the operating life of the cutting tool.

Wear particles 18, 20, 22, and 24, at the point in time shown in Figure 1, are smaller than wear particle 10. Such wear particles tend to congregate within the surfaces imperfections as shown in the figure. With continued interaction between surfaces 12 and 14 and wear particle 10, however, wear particles 18, 20, 22, and 24 may also increase in size to the point where they affect interaction between surfaces 12 and 14 and further add to the problems causing by wear particles the size of wear particle 10. It is apparent that the higher percentage of time each wear particle exists as one of these smaller particles, translates into less wear on the two surfaces 12 and 14. In current applications, wear particles 18, 20, 22, and 24 may became agglomerated on their own or with wear particle 10, adding to the problems it causes, which are described above.

Generally, to reduce wear on surfaces 12 and 14, the wear particles should remain to remain small enough to “hide” in the surface roughness, pits, and grooves of the rubbing surfaces 12 and 14, as do the smaller wear particles 18, 20, 22, and 24. Unfortunately, with continued interaction between surfaces 12 and 14, the agglomerated wear particle 10 will continue to increase in size up to a stable large size determined by material properties and the conditions of contact between the two surfaces 12 and 14. As described above, additional wear action between the surfaces 12 and 14 will result.

The following paragraphs describe how to convert the agglomerated wear particle 10, which is created in the process of rubbing surfaces 12 and 14 together, into a particle that is apt to fall apart or disassemble into smaller particles under the normal and frictional loads typically experienced in such operations. Such a wear particle is created by essentially causing sheer planes or fault lines to be added within wear particles as they agglomerate.

Generally, when thinking of processes that use lubrication, those processes are thought of as being low in friction and also thought of in terms of the part being produced. More specifically, it is generally considered that the part being produced is invariably made from the softer of the two metals in the process, and that the harder metal works the softer metal. As a result, most solutions deal with lubrication and nanoparticles within the lubrication material being used to improve the processing of the part being made.

In contrast, the following embodiments relate more to the tooling that makes such parts, through destabilization, for example through shearing, of the agglomerated wear particle to reduce a rate of wear at both surfaces. These embodiments take advantage of the latest understanding of the interaction at the point of contact between surfaces of the two materials in contact. More specifically, the embodiments describe how to destabilize agglomerated wear particles, which in turn can be utilized to reduce the wear of tooling (and hence recurring cost of tools, drill bits, saws, etc.) in many processes including, for example, stamping, peening, drilling, machining, grinding, polishing, incremental sheet forming, cutting, and punching.

In regard to the shearing of wear agglomerates, the wear agglomerates are formed when wear particles are trapped at the interface and compacted under the large contact pressure (see generally, Oktay, S.T., and Suh, N.P., "Wear particle formation and agglomeration", Journal of Tribology 114, No. 2, (1992) 379-393). Since the wear agglomerate is subjected to the frictional shearing (destabilization) during sliding, lowering the shear strength between compacted particles results in easier breakage of the wear agglomerate. Due to the abundance of oil with dispersed nanoparticles as the lubricating fluid at the interface, nanoparticles adhere to individual wear particles and participate in the wear agglomeration process. The non-limiting examples of nanoparticles described herein, i.e. MoS_2, WS_2, and hBN, are solid lubricants with very low shear strengths (see generally, Kazuhisa Miyoshi, Solid Lubrication Fundamentals & Applications, CRC; 1st edition (October 15, 2001)). Therefore, the shearing of the wear particles within the agglomerate requires less shear force. SEM micrographs have revealed the existence of MoS_2, WS_2, and hBN at the sheared interfaces.

Such embodiments are operable for reducing wear between two components in sliding and rolling contact, rather than reducing friction between the components. Using configurations formulated to reduce wear, rather than formulated to reduce friction, experimental tests have shown up to 70 percent reduction in weight loss of the harder material (the tool or die). It should be noted that a configuration for reducing wear may not be the configuration that results in the least amount of friction.

Figure 2 depicts an agglomerated wear particle 100 that is destabilized through introduction of shear lines therethrough. In one embodiment, destabilization of agglomerated wear particle 100 is achieved by introducing specific nanoparticles 102 into the agglomerated wear particle 100. In one practical application, the nanoparticles 102 are introduced via a lubricating fluid. Other embodiments include introducing the nanoparticles 102 via a dry powder or via a coating on one or more of the parts. Another embodiment contemplates introducing the nanoparticles 102 into the agglomerated wear article 100 as a constituent of one of the two materials that are in sliding contact with one another.

For one embodiment of the present invention, a sonicator was used for dispersing the nanoparticles in the oil samples whose volume was $10\,cm^3$. The sonication was carried out for two periods of five minutes at 10 watts output power while the oil was cooled, via a heat exchanger, with cold water to prevent heating. The concentration of nanoparticles by weight fraction in the oil was varied from a fraction of a percentage to several percentages to study the effect of nanoparticle concentration on friction and wear. The sonication process improved the dispersion quality and reduced the average particle size in the oil compared with simple shaking of oil and nanoparticle solutions. Table 1 shows the dispersion characteristic of nanoparticle in the oil.

Table 1: Nanoparticles and their dispersion characteristics

Materials	Average size (nm) as powder	Average size (nm) in oil after shaking	Average size (nm) in oil after sonication
MoS_2 nanoparticles	70-100	1000	600
WS_2 nanoparticles	50	600	450
hBN nanoparticles	70	800	550

A preliminary result of the introduction of nanoparticles 102 is illustrated by Figure 2. Both the hard surface 110 and the soft surface 112 have lost material therefrom. The lost materials have agglomerated with continued action between surfaces 110 and 112 to generate an agglomerated wear particle 100 through continued sliding contact with one another as described above. However, due to the introduction of the nanoparticles 102 into the area of sliding contact, the wear particle 100 now includes a number of nanoparticles 102 embedded within wear particle 100 which results in shear lines 120 and 122 that extend through the wear particle 100. In certain alternative applications, the nanoparticles 102 are fabricated from one or more solid lubricants, including, but not limited to, molybdenum disulfide (MoS_2), tungsten disulfide (WS_2), and hexagonal boron nitride (hBN), and other solid lubricants such as graphite and others known in the art.

The agglomerated wear particle 10 (shown in Figure 1) consists completely of materials that have worn off of surfaces 12 and 14 and have clustered together into essentially a single particle. One result is that the wear particle acts like a solid mass, as there are no shear lines therethrough. Another result is that wear particle 10 operates on both surfaces 12 and 14, rather than surface 12 operating directly on surface 14.

Wear particle 100 is in contrast because wear particle 100 builds up from the wearing of surfaces 110 and 112, and the clustering of particles therefrom, along with some number of the nanoparticles 102. The presence of the nanoparticles 102 and the resulting shear planes 120 and 122 operate to prevent wear particle 100 from attaining a size similar to that of wear particle 10. More specifically, in the presence of a sufficient pressure against wear particle 100, it will break down into multiple, smaller pieces as shown in Figure 3. As mentioned above, the higher percentage of time such particles spend in the non-agglomerated state reduces the amount of wear between the two surfaces in sliding contact with one another.

Figure 3 illustrates that the agglomerated wear particle 100 of Figure 2 has broken up into multiple, smaller wear particles 150. These smaller wear particles 150 tend to migrate into the valleys 160, 162, 164, and 166, for example, associated with surfaces 110 and 112 thereby reducing the wear on surfaces 110 and 112 associated with wear particle 100 and the like. Two results of the breaking down of agglomerated wear particle 100 are that machining into the soft materials is cleaner, and the cutting device associated with the hard surface 110 lasts longer both of which are illustrated by the lines of cutting area 170.

By adding nanoparticles at a certain percentage by weight, generally to a lubricant associated with that process, those nanoparticles cluster with materials removed from the surfaces to form the agglomerated wear particle 100. It should be noted that nanoparticles themselves may be provided in one or more various shapes including, but not limited to, flakes, balls, and rods. The agglomerated wear particle 100 is sometimes referred to as an abrasive wear ball. This abrasive wear ball breaks apart at the shear planes 120, 122, which are caused by the nanoparticles 102 once a force, such as that which may be introduced by the sliding contact associated with a machining process, is applied. The choice of composition and concentration of nanoparticles added, for example to a lubricant, depends in part on the metals, alloys, composite materials and any other materials that may be used in a machining process. The choice of composition and concentration of nanoparticles added may also be affected by a viscosity associated with the lubricant, for example, maintaining a usable working viscosity of the lubricating fluid, both prior to and after addition of the particular nanoparticles. The reduced size of the separate pieces of the agglomerated wear particle 100 reduces wear on both surfaces.

The embodiments described herein relate to the addition of nanoparticles to an existing work area. There are a host of possible nanoparticles, possible lubricants, and non-lubricant approaches that can be brought to bear against any of a host of machining processes. More specifically, the embodiments relate to the destabilization of agglomerated wear particles, as well as the determination of nanoparticle, and weight percentage of that nanoparticle to use, to gain a significant advantage in the machining process.

Figure 4 is an example graph 200 that illustrates the wear reducing results of adding nanoparticles to a machining process that utilizes titanium sheets against 440C steel balls. Graph 200 illustrates the reduction in wear when molybdenum disulfide (MoS_2), tungsten disulfide (WS_2), or hexagonal boron nitride (hBN), are added to a lubricant in a percentage, by weight from about 0.1 percent to about 10 percent. Graph 200 further illustrates that about 0.5% by weight of tungsten disulfide (WS_2) optimizes the reduction in wear. Graph 200 also illustrates that, for the materials utilized (titanium and steel), tungsten disulfide provides a better reduction in wear rate than does either of hexagonal boron nitride (hBn) and molybdenum disulfide (MoS_2).

Since more than one nanoparticle choice may work for a given pair of surfaces, such as a metal surface pairing, it should be noted that the choice of nanoparticle can be made based on cost and/or a desire to not "gum up" the lubricant being utilized in the machining process by adding too much nanoparticle powder. In one example, a lubricant will effectively contain between about zero and ten percent by weight of a nanoparticle, with a particle size of about 100 nanometers, or less. This percentage will vary depending upon the surface chemistry of the nanoparticles used, the chemistry of the lubricant, and the operating conditions.

Figure 5 is a graph 250, illustrating that maximum wear reduction occurs when adding weight 1% of hexagonal boron nitride (hBN), 4% of molybdenum disulfide (MoS_2), or 4% of tungsten disulfide (WS_2), by weight, to a machining process that includes steel sheets against the 440C steel balls. The hexagonal boron nitride provides dramatic improvements in wear reduction with only a one percent by weight concentration, while slightly better results can be achieved using four times as much MoS_2 or WS_2. While the optimum wear reduction appears to be at about 1% of hexagonal boron nitride (hBN), about 4% of molybdenum disulfide (MoS_2), or about 4% of tungsten disulfide (WS_2), by weight, graph 250 illustrates the reduction in wear when molybdenum disulfide (MoS_2), tungsten disulfide (WS_2), or hexagonal boron nitride (hBN), are added to a lubricant in a percentage, by weight from about 0.1 percent to about 10 percent.

Graph 250 also illustrates a reduction in wear particle production of over 50 percent. A cost component may also be illustrated by the fact that only a one percent concentration of hexagonal boron nitride provides a result that is only slightly reduced from the results associated with a four percent concentration of either MoS_2 or WS_2.

Figure 6 is a graph 300 that illustrates different rates in the reduction in wear of 440C steel balls when different particle concentrations of hexagonal boron nitride, molybdenum disulfide, or tungsten disulfide nanoparticles are added to a lubricant in a process where the steel balls are sliding against steel sheets. The wear in the steel balls, in milligrams per meter, is most reduced when a four percent concentration, by weight, of molybdenum disulfide nanoparticles is added to the lubricant. The reductions in wear of the steel balls when utilizing hexagonal boron nitride or tungsten disulfide nanoparticles, in various concentration, with the lubricant is also shown.

Unlike many nanoparticle uses, the processes described here are insensitive to the uniformity of dispersion of the nanoparticles. Once the nanoparticles are engaged with the wear particles formed in the machining process, the force of the process breaks down agglomerations. However, it is important to keep the nanoparticles in suspension as they are being applied to the machining process. The sonication process described above is but one example of suspension, or dispersion, of the nanoparticles within a lubricant.

The above described embodiments are capable of reducing the weight loss of a hard surface, such as a tool or die by up to 70% as compared to existing oils and lubricants. In addition, the embodiments are also effective in reducing the weight loss of the softer surface, the part being tooled, at least as compared to existing oils and lubricants.

This written description uses examples to disclose various embodiments, which include the best mode, to enable any person skilled in the art to practice those embodiments, including making and using any compositions or systems and performing any incorporated methods. For example, the embodiments may include biocompatible applications, for example, artificial joints, insulin pumps, ventricular assist devices, and others as known in the art. In addition, other applications include vacuum-compatible lubrication (e.g., spacecraft and satellites), contaminate-sensitive manufacturing, and non-outgassing applications. The patentable scope is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A method for reducing wear between two surfaces in contact with one another, with relative motion between the two surfaces, said method comprising:

introducing nanoparticles between the two surfaces in an amount and having a composition that results in shear lines being generated within agglomerated wear particles that are generated between the two surfaces as a result of the sliding contact; and

subjecting the agglomerated wear particles to at least one load, using at least one of the two surfaces, such that the agglomerated wear particles disassemble along the shear lines into multiple smaller wear particles.

2. The method of Claim 1 wherein introducing nanoparticles comprises at least one of:

introducing nanoparticles between the two surfaces via a lubricating fluid;

introducing nanoparticles between the two surfaces via a dry powder;

introducing nanoparticles between the two surfaces via a coating on one or more of the two surfaces; and

introducing nanoparticles between the two surfaces as a constituent of one of the two surfaces in sliding contact.

3. The method of Claim 1 wherein introducing nanoparticles comprises introducing at least one of hexagonal boron nitride (hBN), molybdenum disulfide (MoS_2), and tungsten disulfide (WS_2) to a machining process.

4. The method of Claim 1 wherein introducing nanoparticles comprises introducing between about 0.1 percent and about ten percent by weight of hexagonal boron nitride (hBN) to lubricating fluid utilized between two steel surfaces in sliding contact with one another.

5. The method of Claim 1 wherein introducing nanoparticles comprises introducing between about 0.1 percent and about ten percent by weight of one of molybdenum disulfide (MoS_2) and tungsten disulfide (WS_2) to lubricating fluid utilized between a titanium surface and a steel surface in sliding contact with one another.

6. The method of Claim 1 wherein introducing nanoparticles comprises embedding nanoparticles within at least one agglomerated wear particle.

7. The method of Claim 1 wherein introducing nanoparticles comprises adding a specific nanoparticle, by weight percentage, to at least one of a lubricant and a machining fluid that is to be placed between the two surfaces.

8. The method of any of Claims 1–7 further comprising matching a nanoparticle composition with the materials from which the two surfaces are fabricated to produce a sufficient number of shear lines in at least one agglomerated wear particle to induce disassembly of the particles under load.

9. The method of any of Claims 1–8 further comprising selecting a nanoparticle composition to reduce wear between the two surfaces, using a comparison of the costs of specific nanoparticles against an amount of wear reduction provided by the specific nanoparticles.

10. The method of any of Claims 1–8 further comprising selecting a nanoparticle composition to reduce wear between the two surfaces based on maintaining a usable working viscosity of a lubricating fluid utilized to introduce the nanoparticles to the area between the two surfaces.

11. A method for reducing wear of two surfaces in sliding contact with one another, said method comprising:

destabilizing, using nanoparticles, wear particles that agglomerate between the two surfaces as a result of the sliding contact; and

causing the destabilized, agglomerated wear particles to break down into smaller pieces.

12. The method of Claim 11 wherein destabilizing comprises introducing nanoparticles between the two surfaces in an amount and having a composition that results in shear lines being generated within agglomerated wear particles that are generated between the two surfaces.

13. The method of Claim 11 or 12 wherein causing comprises applying a pressure to the agglomerated wear particles such that the agglomerated wear particles break down along the sheer lines into multiple, smaller wear particles.

14. The method of Claim 11 wherein destabilizing comprises introducing at least one of hexagonal boron nitride (hBN), molybdenum disulfide (MoS_2), and tungsten disulfide (WS_2) to a machining process.

15. The method of Claim 11 wherein destabilizing comprises embedding nanoparticles within agglomerated wear particles.

16. The method of Claim 11 wherein destabilizing comprises adding a specific nanoparticle, by weight percentage, to at least one of a lubricant and a machining fluid that is to be placed between the two surfaces.

17. The method of any of Claims 11–16 further comprising matching a nanoparticle composition with the materials from which the two surfaces are fabricated to produce a sufficient number of shear lines within the agglomerated wear particles to induce disassembly of the particles under load.

18. A composition to produce shear lines of an agglomerated wear particle, comprising:

a fluid lubricant; and

at least 0.1 percent by weight of one or more of particles of molybdenum disulfide (MoS_2), tungsten disulfide (WS_2), and hexagonal boron nitride (hBN), wherein the average particle size in the lubricant is less than 600 nm.

19. The composition of claim 18 wherein the composition particle size is reduced by sonication.

20. The composition of claim 18 or 19 wherein the particle composition weight percentage is between about 0.1 percent and about 10 percent hexagonal boron nitride.

21. The composition of claim 20 wherein the particle composition weight percentage is about one percent hexagonal boron nitride.

22. The composition of claim 18 or 19 wherein the particle composition weight percentage is between about 0.1 percent and about ten percent molybdenum disulfide.

23. The composition of claim 22 wherein the particle composition weight percentage is about four percent molybdenum disulfide.

24. The composition of claim 18 or 19 wherein the particle composition weight percentage is between about 0.1 percent and about ten percent tungsten disulfide.

25. The composition of claim 24 wherein the particle composition weight percentage is about four percent tungsten disulfide.

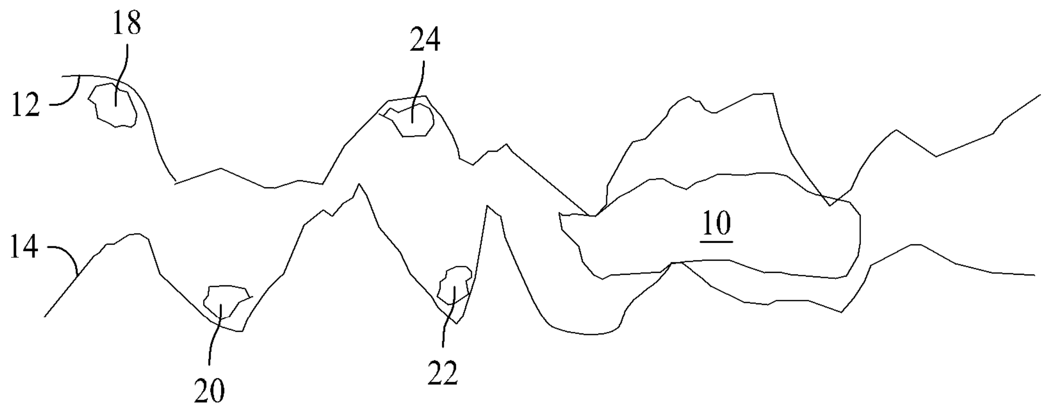


FIG. 1

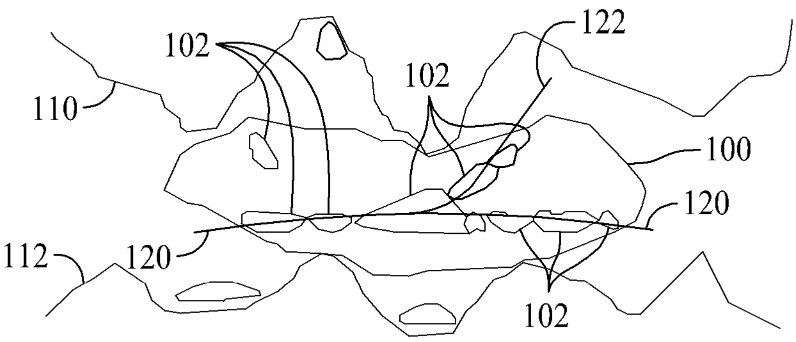


FIG. 2

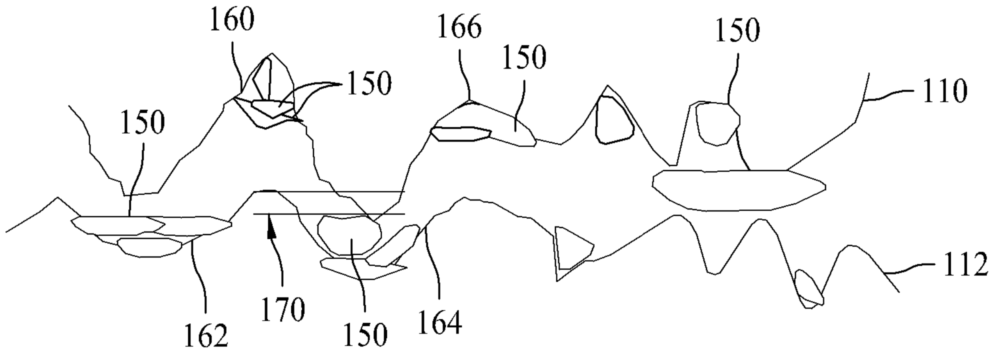
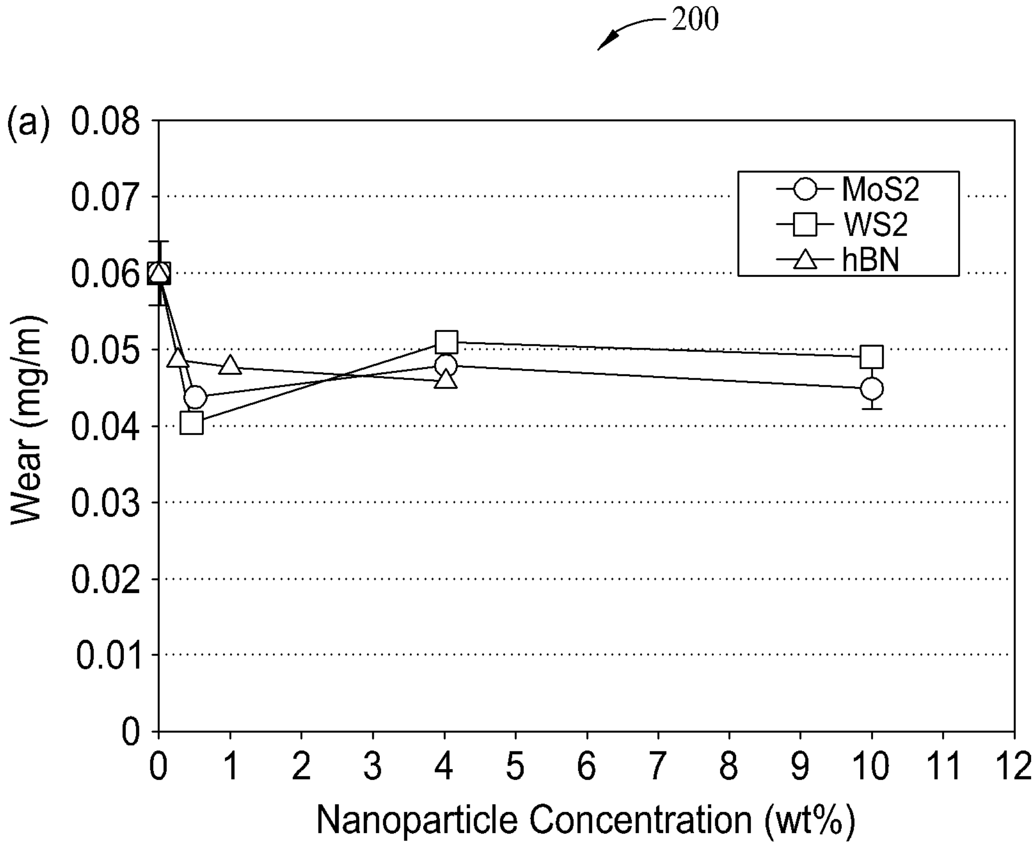


FIG. 3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(a)
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0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Wear (mg/m)
MoS2
WS2
hBN
0 1 2 3 4 5 6 7 8 9 10 11 12
Nanoparticle Concentration (wt%)

FIG. 4

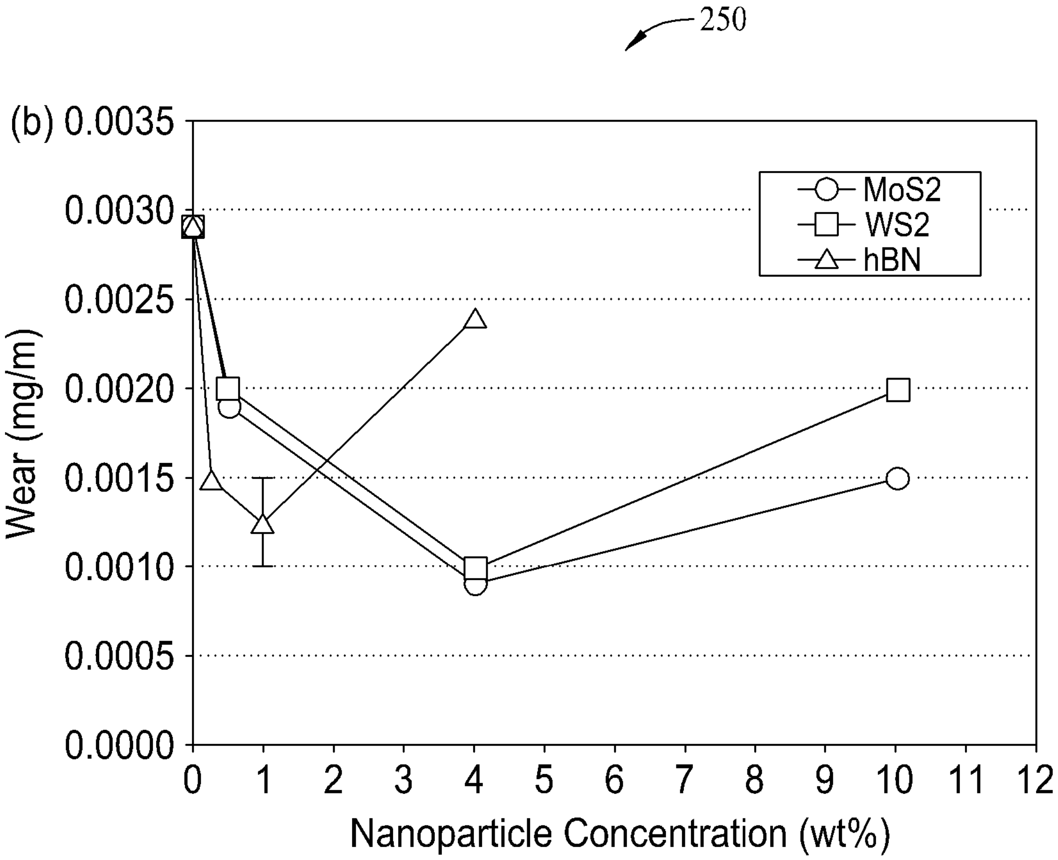
250
(b)
Wear (mg/m)
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
MoS2
WS2
hBN
0
1
2
3
4
5
6
7
8
9
10
11
12
Nanoparticle Concentration (wt%)

FIG. 5

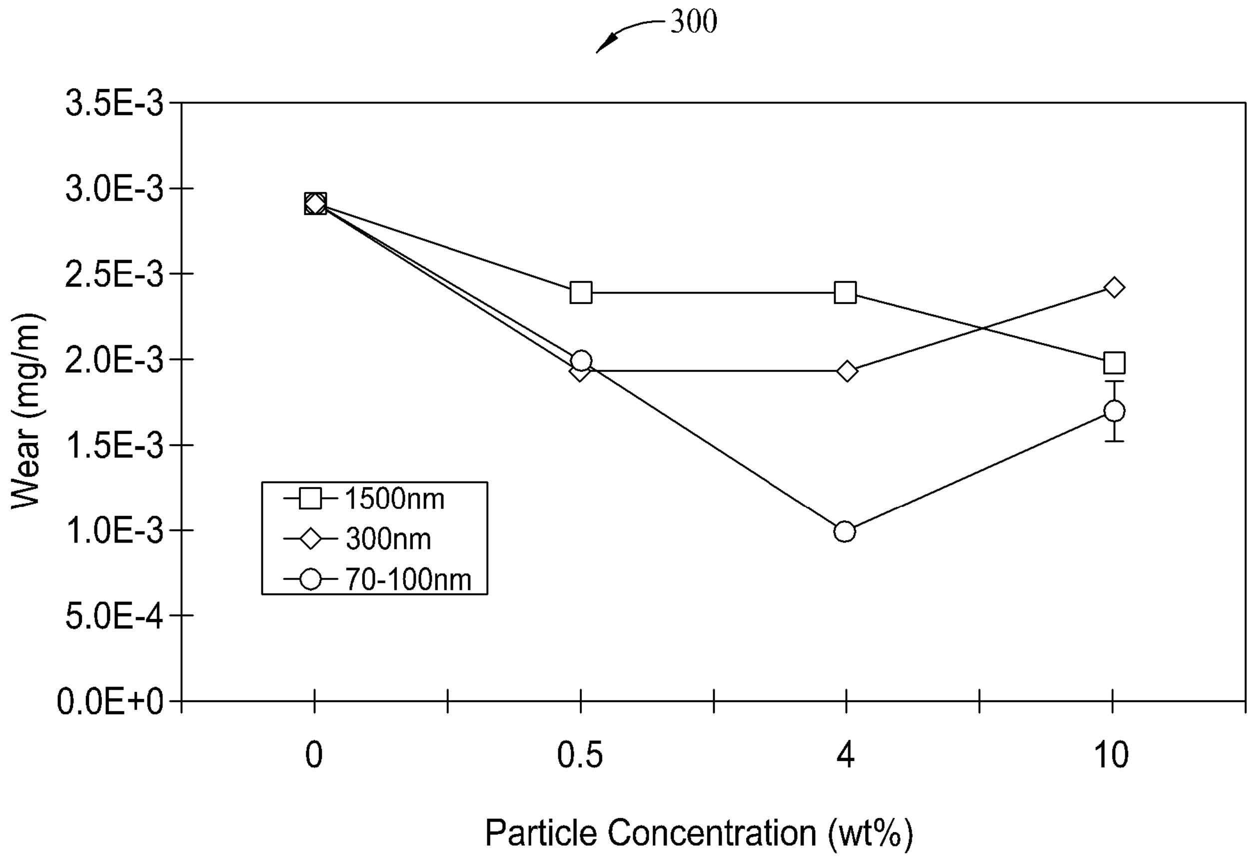
300
3.5E-3
3.0E-3
2.5E-3
2.0E-3
1.5E-3
1.0E-3
5.0E-4
0.0E+0
Wear (mg/m)
1500nm
300nm
70-100nm
0
0.5
4
10
Particle Concentration (wt%)

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/029981

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10M103/00 C10M103/06 C10M125/20 C10M125/22
ADD. C10N10/12 C10N20/06 C10N40/22 C10N50/08 C10N70/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C10M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 10 130678 A (OTSUKA CHEMICAL CO LTD) 19 May 1998 (1998-05-19) * abstract paragraph [0017] - paragraph [0020] -----	18-21
X	RAPOPORT L ET AL: "Fullerene-like WS2 nanoparticles: superior lubricants for Harsh conditions" ADVANCED MATERIALS, vol. 15, no. 7-8, 17 April 2003 (2003-04-17), pages 651-655, XP002575459 WILEY VCH VERLAG, DE ISSN: 0935-9648 DOI: 10.1002/ADMA.200301640 [retrieved on 2003-04-09] page 652, right-hand column, paragraph 2 - page 655, left-hand column, paragraph 2 -----	1-7, 11-19, 24,25

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 July 2010	11/08/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kazemi, Pirjo

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CIZAIRE L ET AL: "Mechanisms of ultra-low friction by hollow inorganic fullerene-like MoS2 nanoparticles" SURFACE AND COATINGS TECHNOLOGY, vol. 160, no. 2-3, 22 October 2002 (2002-10-22), pages 282-287, XP002591560 ELSEVIER NL DOI: 10.1016/S0257-8972(02)00420-6 * abstract; table 1	1,2,4, 11-16, 18,19, 22,23
X	HUANG H D ET AL: "Friction and Wear Properties of IF-MoS2 as Additive in Paraffin Oil" TRIBOLOGY LETTERS, vol. 20, no. 3-4, 1 December 2005 (2005-12-01), pages 247-250, XP019292546 KLUWER ACADEMIC PUBLISHERS-PLENUM PUBLISHERS, NL ISSN: 1573-2711 figures 2a,4,5,6	1,2,4, 6-8, 11-19, 22,23
X	SHEN B ET AL: "Performance of novel MoS2 nanoparticles based grinding fluids in minimum quantity lubrication grinding" TRANSACTIONS OF THE NORTH AMERICAN MANUFACTURING RESEARCHINSTITUTION OF SME, vol. 36, 1 May 2008 (2008-05-01), pages 357-364, XP009136140 DEARBORN, MI ISSN: 1047-3025 Experimental details; page 358 - page 359	1-3,7, 18,22,23
X	WO 2007/082299 A2 (UNIV ARKANSAS [US]; MALSHE AJAY P [US]; VERMA ARPANA [US]) 19 July 2007 (2007-07-19) paragraphs [0036], [0044], [0045], [0050]; claims 71,77,90,91; figures 2,3; examples; table 2	18-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/029981

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
JP 10130678	A	19-05-1998	NONE			
WO 2007082299	A2	19-07-2007	CA	2636932	A1	19-07-2007
			CN	101379168	A	04-03-2009
			EP	1973998	A2	01-10-2008
			JP	2009523863	T	25-06-2009
			US	2008312111	A1	18-12-2008