



US 20130302173A1

(19) **United States**

(12) **Patent Application Publication**
Booze et al.

(10) **Pub. No.: US 2013/0302173 A1**

(43) **Pub. Date: Nov. 14, 2013**

(54) **WEAR RESISTANT TURBINE FAN BLADE**

Publication Classification

(75) Inventors: **J. David Booze**, Wilmington, DE (US);
Clifford K. Deakyne, Wilmington, DE (US);
Frederic Pailler, Forest (BE);
James E. Weishampel, Amherst, OH (US)

(51) **Int. Cl.**
F01D 5/14 (2006.01)
(52) **U.S. Cl.**
USPC **416/230**

(73) Assignee: **E. I. DU PONT DE NEMOURS AND COMPANY**, Wilmington, DE (US)

(57) **ABSTRACT**

(21) Appl. No.: **13/469,368**

The disclosure generally relates to a wear resistant turbine fan blade having a composite lubricated sheet adhered to a root of the turbine fan blade and having improved tribological properties at high temperatures.

(22) Filed: **May 11, 2012**

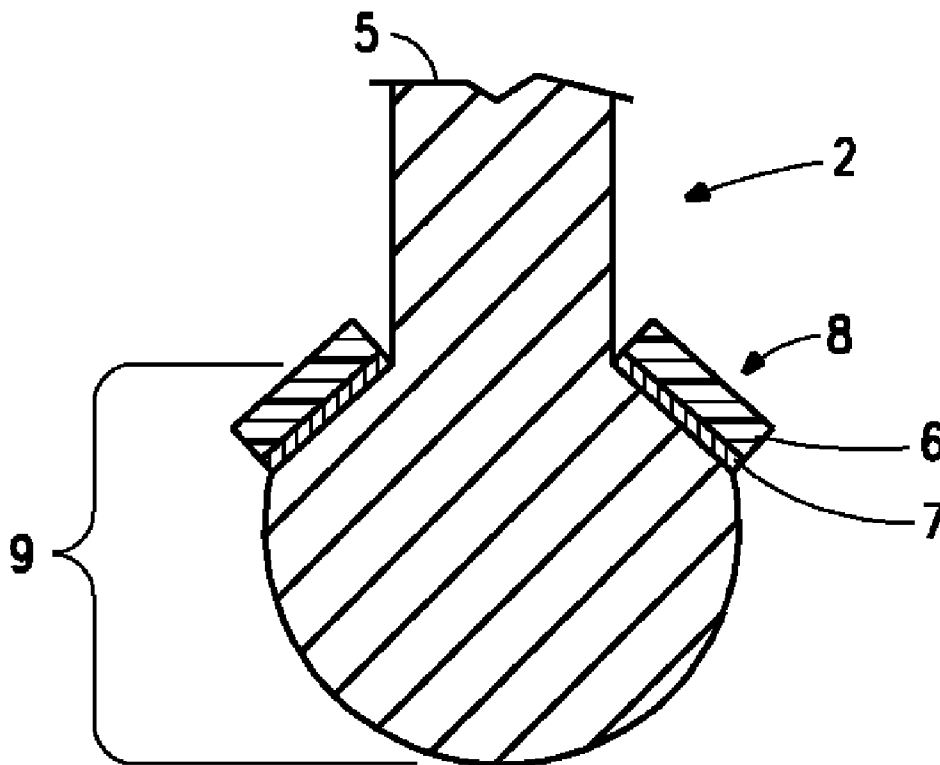


FIG. 1

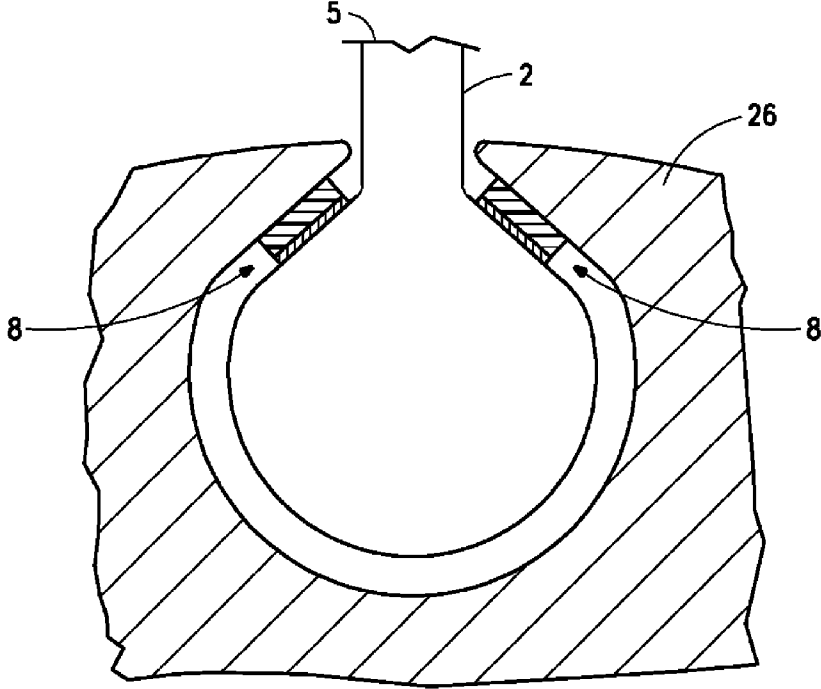
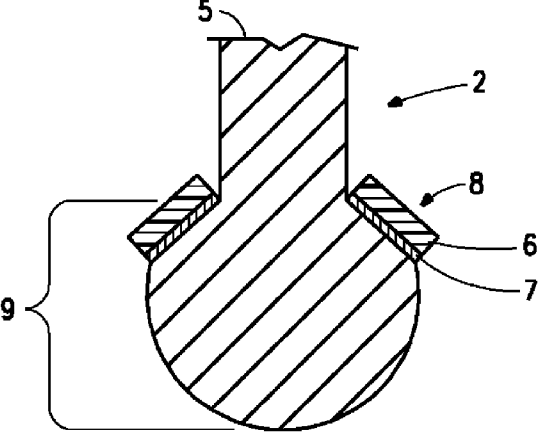


FIG. 2

WEAR RESISTANT TURBINE FAN BLADE

FIELD OF THE INVENTION

[0001] The disclosure generally relates to wear resistant turbine fan blades; more particularly to wear resistant turbine fan blades having a composite lubricating sheet adhered to a root of the turbine fan blade.

BACKGROUND OF THE INVENTION

[0002] Typically, a wear resistant turbine fan blade is used to prevent or to reduce friction and wear when in sustained contact with other objects due to relative motion of both under high load and/or frictional forces.

SUMMARY OF THE INVENTION

[0003] A first aspect of the present invention relates to a wear resistant turbine fan blade comprising: a composite lubricating sheet adhered to a root of the turbine fan blade, wherein the composite lubricating sheet comprises: a fabric at least partially embedded with a resin, the fabric including an aromatic polyamide yarn, and a mixed yarn having the aromatic polyamide yarn and a low-friction yarn; and a metallic layer adhered to one side of the fabric.

[0004] A second aspect of the present invention relates to a turbine engine including at least one turbine fan blade having a composite lubricating sheet adhered to a root of the turbine fan blade, wherein the composite lubricating sheet comprises: a fabric at least partially embedded by a resin, the fabric including an aromatic polyamide yarn and a mixed yarn having the aromatic polyamide yarn and a low-friction yarn; and a metallic layer adhered to one side of the resin embedded fabric.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] These and other features of this invention will be more readily understood from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings that depict various embodiments of the invention, in which:

[0006] FIG. 1 depicts an embodiment of a wear resistant turbine fan blade, in accordance with the present disclosure.

[0007] FIG. 2 depicts an embodiment of a wear resistant turbine fan blade in use with a rotor disk.

[0008] It is noted that the drawings of the invention are not to scale. The drawings are intended to depict only typical aspects of the invention, and therefore should not be considered as limiting the scope of the invention. In the drawings, like numbering represents like elements between drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0009] Fan blades used in the aerospace industry, and in particular, in turbine engines are often subjected to high pressure loads and high frictional forces between the fan blades and other objects in contact with the fan blades resulting in surface wear and crack formation due to fatigue stress of the fan blades and/or objects in turbine engines. Improvements in the wear resistance of fan blades is sought so as to improve the lifespan of the fan blades and/or objects in contact with the fan blades; to reduce the maintenance time of turbine engines; and to increase the operational time of a device, assembly, airplane, etc. that incorporate such fan blades. Wear means the deterioration of any properties of a solid surface by the

action of another surface. The deteriorated properties may include, but are not limited to, thickness, smoothness, hardness, strength, and/or integrity. It has been discovered that the wear resistance of a fan blade may be improved or increased by having a composite lubricating sheet adhered to a root of the fan blade where the composite lubricating sheet has a metallic layer.

[0010] An embodiment of a wear resistant turbine fan blade is shown in FIG. 1, in accordance with the present disclosure. Referring to FIG. 1, a wear resistant turbine fan blade 2 is shown having composite lubricating sheets (CLS) 8 adhered thereon. In particular, the CLSs 8 are adhered to a root 9 of turbine fan blade 2. Reference 5 connotes that turbine fan blade 2 may continue beyond reference 5 to form a larger, complete turbine fan blade. Turbine fan blade 2 may be an integrated component in a turbine engine, a rotor disk, and a rotor disk assembly. Turbine fan blade 2 may comprise a metal selected from titanium, aluminum, steel, nickel, and alloys thereof. In an embodiment, turbine fan blade 2 may comprise titanium. In another embodiment, turbine fan blade 2 may comprise steel. In another embodiment, turbine fan blade 2 may comprise aluminum.

[0011] CLS 8 may comprise a fabric 6 and a metallic layer 7 adhered to one side of fabric 6. Fabric 6 may be at least partially embedded with a resin, and may include an aromatic polyamide yarn and a mixed yarn having the aromatic polyamide yarn and a low-friction yarn. The aromatic polyamide yarn may be a plurality of fibers in a bundle, including fiber comprising an aromatic polyamide, used for weaving. The aromatic polyamide yarn may include yarns made from but not limited to poly(para-phenylene terephthalamide), poly(meta-phenylene terephthalamide), poly(meta-phenylene isophthalamide), poly(para-phenylene isophthalamide), combinations thereof, and copolymers thereof.

[0012] The low-friction yarn may be a yarn having a coefficient of friction (COF) against itself which is lower than the COF of the aromatic polyamide yarn against itself. The low-friction yarn may comprise graphite or a fluoropolymer. In an embodiment, the low-friction yarn may comprise graphite fiber or a fluoropolymer fiber. In an embodiment, the fluoropolymer fiber may be polytetrafluoroethylene fiber. Resin embedded fabric 6 may be at least partially embedded with a resin selected from, but not limited to, a phenolic resin, an epoxy resin, or a polyimide resin. In an embodiment, the phenolic resin may comprise phenol-formaldehyde.

[0013] Metallic layer 7 may comprise a metal selected from titanium, aluminum, steel, and nickel. In an embodiment, metallic layer 7 may be titanium. In another embodiment, metallic layer 7 may be steel. Metallic layer 7 may have a thickness in a range from approximately 20 microns to approximately 1,000 microns. In an embodiment, metallic layer 7 may have a thickness in a range from approximately 50 microns to approximately 250 microns. In another embodiment, metallic layer 7 may have a thickness in a range from approximately 70 microns to approximately 100 microns. In another embodiment, metallic layer 7 may have a thickness of approximately 90 microns.

[0014] Metallic layer 7 may be in the form a metallic foil. In an embodiment, the metallic foil may be a thin, flexible sheet of titanium, aluminum, steel, or nickel. In an embodiment, metallic layer 7 may be a titanium foil. In another embodiment, the metallic foil may have a thickness in a range from approximately 20 microns to approximately 1,000 microns. In another embodiment, the metallic foil may have a thickness

in a range from approximately 50 microns to approximately 250 microns. In another embodiment, the metallic foil may have a thickness in a range from approximately 70 microns to approximately 100 microns. In another embodiment, the metallic foil may have a thickness of approximately 90 microns. Metallic layer 7 may be adhered to one side of resin embedded fabric 6.

[0015] In an embodiment, metallic layer 7 may be a pure metal comprising a single metallic element. In another embodiment, metallic layer 7 may be a metal alloy comprising two or more metallic elements. When two or more metallic elements are a part of metallic layer 7, any element may be a major or predominant element by weight percent. Embodiments of elements present in metallic layer 7 include, but are not limited, to titanium, iron, aluminum, copper, nickel, zinc, tungsten, molybdenum, tin, and cobalt. Any of the aforementioned elements may be the major or predominant element by weight percent.

[0016] Metallic layer 7 may have a Vickers hardness value HV of approximately 30 or greater at a load of 100 g applied for 20 seconds according to ASTM E-384. In an embodiment, metallic layer 7 may have a Vickers HV of approximately 100 or greater. In another embodiment, metallic layer 7 may have a Vickers HV of approximately 200 or greater. In another embodiment, metallic layer 7 may have a Vickers HV of approximately 300 or greater.

[0017] An example of composite lubricating sheet 8 having a titanium metallic layer 7 is Vespel® ASB-0670 product grade available from E.I. du Pont de Nemours and Company. Other Vespel® composite lubricating sheet 8 product grades may include metallic layer 7 being steel, aluminum, or nickel.

[0018] Composite lubricating sheet (CLS) 8 may have a thickness in a range from 30 microns to 3 mm. In embodiment, CLS 8 may have a thickness in a range from 50 microns to 1 mm. In another embodiment, the thickness may be in a range from 100 microns to 750 microns.

[0019] CLS 8 may have a Compression Fraction value in a range from 0.1% (0.001) to approximately 20% (0.20) with a pressure applied by compressing at approximately 127 microns/minute up to approximately 450 MPa and then released. Compression Fraction means the fraction of thickness lost due to compression under specific conditions. In an embodiment, composite lubricating sheet 8 may have a Compression Fraction value in a range from 1% (0.010) to approximately 5.7% (0.057). In another embodiment, the Compression Fraction value may be in a range from 1.3% (0.013) to approximately 3% (0.030). The aforementioned Compression Fraction value embodiments may be determined with a pressure applied by compressing at approximately 127 microns/minute up to approximately 450 MPa and then released.

[0020] CLS 8 may be adhered to turbine fan blade root 9 to form wear resistant turbine fan blade 2. The adherence of CLS 8 may be achieved through physical or chemical bonding. One may also use an adhesive such as thermoplastic adhesive, a thermoset adhesive, and other bonding adhesives known in the art. In particular, metallic layer 7 may be adhered to blade root 9. In an embodiment, the thermoset adhesive may be an epoxy adhesive. The bonding adhesive layer may have a thickness in range from approximately 2 microns to 2,000 microns. In an embodiment, the thickness may be in a range from approximately 10 microns to 100 microns. In another embodiment, the thickness may be in a range from approximately 20 microns to 80 microns.

[0021] Prior to adhering CLS 8 to blade root 9, the surface of metallic layer 7 to be adhered to blade root 9 and/or the surface of blade root 9 may be surface treated. Surface treatment may be performed by any known process in the art to treat a metallic surface. In an embodiment, surface treatment may be performed by a peening process. Typical peening processes involve the impacting a surface with numerous, small particles. An example of a peening process is shot peening. The shot-peened, roughened surface may have a characteristic roughness identifiable by the appearance of small craters in the surface. In another embodiment, surface treatment may include sandblasting the surface of metallic layer 7 to be adhered to blade root 9 and/or sandblasting the surface of blade root 9. In another embodiment, surface treatment may include chemical etching of the surface of metallic layer 7 to be adhered to blade root 9 and/or chemical etching the surface of blade root 9. In another embodiment, surface treatment may include belt sanding of the surface of metallic layer 7 to be adhered to blade root 9 and/or belt sanding the surface of blade root 9.

[0022] The aforementioned surface treatments may be performed in combination to treat the surface of metallic layer 7 and/or the surface of blade root 9. For example, the surface of metallic layer 7 to be adhered to blade root 9 may be first shot-peened and then the shot peened surface may be treated by sandblasting prior to adhesion to blade root 9.

[0023] During normal use, the wear resistant turbine fan blade 2 disclosed herein may typically come in sustained contact and movement, through resin embedded fabric 6 of composite lubricating sheet 8, with another object(s) under a high pressure load and under vibratory, reciprocating, and/or circular motions. The high pressure load may be in a range from approximately 100 MPa to approximately 600 MPa. Wear resistant turbine fan blade 2 in sustained contact with another object may have a Coefficient of Friction (COF) value in a range from 0.01 to 0.1. In an embodiment, the COF value may be less than approximately 0.05. In another embodiment, the COF value may be less than 0.04.

[0024] The utility of wear resistant turbine fan blade 2 may be demonstrated by measuring the durability of CLS 8 under controlled pressure and wear conditions. Wear under pressure may be demonstrated, for example, by: providing a body having a surface subject to wear, such as a titanium block with a known roughness; adhering to the surface subject to wear composite lubricating sheet 8 wherein the adhering occurs between the metallic layer 7 and the titanium surface subject to wear; providing an object having a wear surface such as another titanium block; aligning resin embedded fabric 6 of CLS 8 with the wear surface of the other object with a pressure in a range from approximately 210 MPa to approximately 500 MPa; and causing resin embedded fabric 6 of CLS 8 to be in sustained contact with the surface of the other object.

EXAMPLES

[0025] The present disclosure may be further defined by the following examples. It should be understood that the following examples, while indicating embodiments of the present disclosure, are given by way of illustration only. From the above discussion and the following examples, one having ordinary skill in the art can ascertain the essential characteristics of the present disclosure, and without departing from

the spirit and scope thereof, may make various changes and modifications of the present disclosure to adapt it to various uses and conditions.

[0026] Table 1 lists Vickers Hardness values (HV) for metallic layer 7 of composite lubricating sheet (CLS) 8. Values listed in Table 1 are for metallic layer 7 in the form of a metallic foil. Vickers Hardness values are described in ASTM E-384 which is incorporated herein by reference in its entirety. Unless otherwise specified, HV in Table 1. means HV 0.1/20 as determined with 100 gram force applied for 20 seconds.

TABLE 1

Designation	Foil-1	Foil-2	Foil-3	Foil-4	Foil 5	Foil-6
Material	Fe	Ti	Ti	Ti	Al	Al
Foil	Stainless	ASTM	ASTM			
Descrip- tion	Steel, Type 304	B265, Grade = 4	B265, Grade = 9			
Thickness (microns)	75	70	90	460	125	125
Metallic layer						
Hardness, HV 0.1/20	407	252	224	176	39.1	23*
HV Std Dev	13	10	2.5	6.4	0.3	0.8

*Foil-6 Hardness HV is determined with 50 g for 20 seconds (HV 0.05/20)

[0027] CLS 8 of the present disclosure may be resistant to crushing by compressive forces. In one embodiment, a suitable test for resistance to compressible forces is to determine the fraction of compression that a strong compressive force produces. Table 2 lists Compression Fraction percentage values for CLS 8 having various metallic layers 7 and an entry (10) for CLS 8 without a metallic layer for comparison.

TABLE 2

CLS	1	2	3	4	5	6	C1
Metallic Layer	Fe	Ti	Ti	Ti	Al	Al	None
Thickness, microns	370	370	400	800	460	435	280
Compression Fraction, %	2.6	1.6	2.8	1.42	5.83	6.55	8.63

[0028] In Table 2, CLS test samples 2, 3, and 4 are representative samples of Vespel ASB-0670 product grade available from E.I. du Pont de Nemours and Company in which the metallic layer is titanium. CLS test samples 1, 5, and 6 are representative samples of other Vespel® composite lubricating sheet 8 product grades in which the metallic layer 7 is steel (Fe) and aluminum. CLS test sample C1 is a comparative sample in which it does not have a metallic layer 7.

[0029] Compression fraction percentage values of CLSs 8 were determined using a Mitutoyo IP 54 micrometer and an Instron 1332 fatigue system with an 8800 controller. The Mitutoyo IP 54 micrometer was used to measure thickness of CLS by first measuring the initial thickness of a CLS square of approximately 25 mm by approximately 25 mm. The Instron 1332 fatigue system was used to apply compressive loads to the CLS square. The measured CLS square was then compressed with a 10 mm by 10 mm shot-peened surfaced Ti block to 450 MPa applied at 0.05 inch/min (1270 microns/min) using the Instron 1332 fatigue system. When 450 MPa

pressure was achieved, the pressure was released and measurement of the final thickness of the CLS square was made within one minute using the Mitutoyo IP 54 micrometer.

[0030] CLS 8 of the present disclosure may be resistant to crushing by compressive forces and wear through rubbing/frictional forces. In one embodiment, a suitable test for resistance to compressible forces and simultaneous frictional force is to determine the Minimum Strokes number CLS 8 may sustain before succumbing to failure. Table 3 lists Minimum Strokes values for CLS 8 having a titanium metallic layer 7 and for CLS 8 without a metallic layer for comparison.

TABLE 3

CLS	1*	2*	3
Metallic Layer	Ti	Ti	None
Pressure, MPa	400	400	400
Minimum Strokes	43,527	44,244	362

*Two sets of test specimens used.

[0031] In Table 3, CLS test samples 1 and 2 are representative samples of Vespel® ASB-0670 product grade available from E.I. du Pont de Nemours and Company in which the metallic layer is titanium. CLS test sample C1 is a comparative sample in which it does not have a metallic layer 7.

[0032] Minimum Strokes values of CLSs 8 in use with a metal substrate were determined using an Instron 1321 fatigue system with an 8800 controller. The Minimum Strokes values were reported as the number of reciprocating test strokes of 1.2 mm in length applied at 10 Hz accomplished by the relative motion of the article with respect to resin embedded fabric layer 6 of CLS 8.

[0033] Prior to evaluating wear under pressure, the resin embedded fabric layer 6 of CLS 8 was lightly coated with a lubricant containing a fluorochemical by spraying or painting the lubricant on the surface of the resin embedded fabric layer 6. The spraying or coating provides a thin translucent to an opaque coating of lubricant.

[0034] CLS 8 was adhered to a stationary metal substrate by an epoxy adhesive such as for example, NB 101 available from Newport Adhesives and Composites, Inc; Irvine, Calif. The stationary metal substrate was a sandblasted, 20 mm by 20 mm titanium block with a peen-hardened surface having a Rockwell C33 hardness. The metallic layer of CLS 8 was adhered to the titanium block with resin embedded fabric layer 6 of CLS 8 facing away from the titanium block. The adhesive was oven cured under low pressure (approximately 5 psi) comprising a first heating step to approximately 79° C. for 90 min and then a second heating step to approximately 149° C. for an hour. The titanium block was then mounted in the lower carrier of the Instron 1321 with CLS 8 facing up.

[0035] A second titanium block with a peen-hardened surface (Rockwell C33 hardness) measuring approximately 10 mm by 10 mm and microns was mounted in an upper carrier of the Instron 1321 and brought into parallel reversible contact with CLS 8 aligned in the center of the titanium block in the lower carrier. The pressure between the blocks was raised to 400 MPa, and reciprocating strokes were applied at a rate of 10 forward and 10 backward strokes per second with a stroke length of 1.2 mm. Testing was run until the onset of failure, i.e., a corner of the 10 mm by 10 mm titanium block penetrated resin embedded fabric layer 6 of CLS 8. The Minimum Strokes value represents the number of strokes to reach

test specimen failure. The larger the Minimum Strokes value, the better the performance of CLS 8.

[0036] Comparing CLS test samples 1 and 2 having a titanium metallic layer (VespeI® ASB-0670 product grade) to comparative test sample C1 not having a metallic layer, an approximate 100 fold improvement in wear resistance was achieved for test samples 1 and 2. Under test conditions, a value greater than 10,000 Minimum Strokes represents durability to last through, for example, an engine maintenance cycle.

[0037] Another embodiment of a wear resistant turbine fan blade is shown in FIG. 2, in accordance with the present invention. Referring to FIGS. 1 and 2, a wear resistant turbine fan blade 2 is shown having composite lubricating sheets (CLS) 8 adhered on turbine fan blade root 9. Turbine fan blade 2 may be an integrated component in a turbine engine. Embodiments of turbine fan blade 2 and CLS 8 have been previously described and are herein incorporated by reference in their entirety.

[0038] CLSs 8 may protect fan blade root 9 from deterioration when in use with, for example, a rotor disk 26. The forces and loads experienced between fan blade root 9 and rotor disk 26 during operation of a turbine engine are known in the art. Performance characteristics of composite lubricating sheet 8 have been previously described and are herein incorporated by reference in their entirety. The performance tests conducted are representative of the forces and loads experienced between fan blade root 9 and rotor disk 26 during operation of a turbine engine. In another embodiment, CLS 8 may be adhered to a metal substrate such as a shim, metallic layer, or any part already adhered to fan blade root 9. The shim, metallic layer, etc. may comprise a metal selected from titanium or steel.

[0039] An embodiment of a turbine engine is described, in accordance with the present invention. The turbine engine may include at one turbine fan blade having a composite lubricated sheet adhered thereon. Embodiments and performance characteristics of the composite lubricating sheet have been previously described and are herein incorporated by reference in their entirety. Embodiments of the turbine fan blade having a composite lubricating sheet adhered therein have been previously described.

[0040] The terms “first”, “second”, and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another, and the terms “a” and “an” herein do not denote a limitation of quantity, but rather denotes the presence of at least one of the referenced items. The modifier “about” used in connection with a quantity is inclusive of the state value and has the meaning dictated by the context, (e.g., includes the degree of error associated with measurement of the particular quantity). The suffix “(s)” as used herein is intended to include both the singular and the plural of the term that it modifies, thereby including one or more of that term (e.g., the metal(s) includes one or more metals). Ranges disclosed herein are inclusive and independently combinable (e.g., ranges of “to approximately 25 wt %”, or, more specifically, approximately 5 wt % to approximately 20 wt %”, is inclusive of the endpoints and all intermediate values of ranges of “approximately 5 wt % to approximately 25 wt %”, etc.)

[0041] While various embodiments are described herein, it will be appreciated from the specification that various embodiments of elements, variations or improvements therein may be made by those skilled in the art, and are within

the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A wear resistant turbine fan blade comprising:
 - a composite lubricating sheet adhered to a root of the turbine fan blade, wherein the composite lubricating sheet comprises:
 - a fabric at least partially embedded with a resin, the fabric including an aromatic polyamide yarn, and a mixed yarn having the aromatic polyamide yarn and a low-friction yarn; and
 - a metallic layer adhered to one side of the fabric.
2. The turbine fan blade according to claim 1, wherein the turbine fan blade is an integrated component of a machine selected from the group consisting of a rotor disk, a rotor assembly, and a turbine engine.
3. The turbine fan blade according to claim 2, wherein the turbine fan blade is an integrated component of a turbine engine.
4. The turbine fan blade according to claim 1, wherein the turbine fan blade comprises a metal selected from the group consisting of titanium, aluminum, steel, nickel, and alloys thereof.
5. The turbine fan blade according to claim 4, wherein the turbine fan blade is titanium.
6. The turbine fan blade according to claim 1, wherein the resin is phenol-formaldehyde resin.
7. The turbine fan blade according to claim 1, wherein the aromatic polyamide yarn is selected from the group consisting of poly(para-phenylene terephthalamide), poly(meta-phenylene terephthalamide), poly(meta-phenylene isophthalamide), poly(para-phenylene isophthalamide), combinations thereof, and copolymers thereof.
8. The turbine fan blade according to claim 1, wherein the low-friction yarn comprises graphite fiber or a fluoropolymer fiber.
9. The turbine fan blade according to claim 8, wherein the fluoropolymer fiber comprises a polytetrafluoroethylene.
10. The turbine fan blade according to claim 1, wherein the metallic layer is a metal selected from the group consisting of titanium, aluminum, steel, and nickel.
11. The turbine fan blade according to claim 10, wherein the metallic layer is titanium.
12. The turbine fan according to claim 1, wherein the metallic layer has a thickness in a range from approximately 50 microns to approximately 250.
13. The turbine fan blade according to claim 1, wherein the metallic layer has a Vickers Hardness of approximately 30 HV or greater at a load of approximately 100 grams applied for approximately 20 seconds according to ASTM E-384.
14. The turbine fan blade according to claim 1, wherein the composite lubricating sheet has a Compression Fraction in a range of 0.1% to approximately 20% with a pressure applied by compressing at approximately 127 microns/minute up to approximately 450 MPa and then released.
15. The turbine fan blade according to claim 1, wherein the composite lubricating sheet additionally comprises an attaching layer between the fabric and the metallic layer, attaching

layer comprising an adhesive selected from the group consisting of a thermoplastic adhesive or a thermoset adhesive.

16. A turbine engine including at least one turbine fan blade having a composite lubricating sheet adhered to a root of the turbine fan blade, wherein the composite lubricating sheet comprises:

- a fabric at least partially embedded by a resin, the fabric including an aromatic polyamide yarn and a mixed yarn having the aromatic polyamide yarn and a low-friction yarn; and
- a metallic layer adhered to one side of the resin embedded fabric.

17. The turbine engine according to claim **16**, wherein the aromatic polyamide yarn is selected from the group consisting of poly(para-phenylene terephthalamide), poly(meta-phenylene terephthalamide), poly(meta-phenylene isophthalamide), poly(para-phenylene isophthalamide), combinations thereof, and copolymers thereof; and the low-friction yarn comprises graphite or a fluoropolymer.

18. The turbine engine according to claim **16**, wherein the metallic layer is a metal selected from the group consisting of titanium, aluminum, steel, and nickel.

19. The turbine engine according to claim **16**, wherein the metallic layer has a Vickers Hardness of approximately 30 HV or greater at a load of approximately 100 grams applied for approximately 20 seconds according to ASTM E-384.

20. The turbine engine according to claim **16**, wherein the composite lubricating sheet has a Compression Fraction in a range of 0.1% to approximately 20% with a pressure applied by compressing at approximately 127 microns/minute up to approximately 450 MPa and then released.

* * * * *