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United States Patent	12392244
Kind Code	B2
Date of Patent	August 19, 2025
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Repair process using plasma etching

Abstract

A repair process includes providing a gas turbine engine article that has an elastomeric coating that has an eroded region, plasma etching the elastomeric coating in the eroded region, and applying an elastomeric repair coating on the eroded region.

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Appl. No.: 18/336933

Filed: June 16, 2023

Prior Publication Data

Document Identifier	Publication Date
US 20240418088 A1	Dec. 19, 2024

Publication Classification

Int. Cl.: F01D5/00 (20060101); B05D3/14 (20060101); F01D5/28 (20060101)

U.S. Cl.:

CPC F01D5/005 (20130101); B05D3/142 (20130101); F01D5/288 (20130101); B05D2202/25 (20130101); B05D2530/00 (20130101); F05D2230/80 (20130101); F05D2230/90 (20130101); F05D2300/121 (20130101); F05D2300/431 (20130101); F05D2300/611 (20130101)

Field of Classification Search

CPC: F01D (5/005); F01D (5/288); B05D (3/142); B05D (2202/25); B05D (2530/00); B05D (5/005); F05D (2230/80); F05D (2230/90); F05D (2300/121); F05D (2300/431); F05D (2300/611); F05D (2230/12); F05D (2300/43); F05D (2300/437); F05D (2220/36); B29L (2031/08); B29L (59/14); B29C (73/02)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
8709545	12/2013	Larson-Smith et al.	N/A	N/A
10094220	12/2017	Vontell, Sr. et al.	N/A	N/A
11408371	12/2021	Holland et al.	N/A	N/A
2001/0014409	12/2000	Cohen	205/70	H01L 21/2885
2002/0045053	12/2001	Hoskin	427/446	F01D 5/005
2005/0161439	12/2004	Wustman	216/103	F01D 5/005
2007/0231156	12/2006	Hong	N/A	N/A
2011/0206533	12/2010	Lee	29/889.1	F01D 9/02
2012/0148769	12/2011	Bunker	427/446	F01D 5/186
2014/0127516	12/2013	Wang	528/53	C08J 7/0427
2016/0186609	12/2015	Holland	156/60	F16B 5/04
2016/0200936	12/2015	Steinmetz	560/190	B05D 7/532
2017/0226873	12/2016	Bogue	N/A	B29C 73/10
2022/0333551	12/2021	Holland	N/A	B29C 73/10

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
102680527	12/2011	CN	N/A
109317377	12/2018	CN	N/A
111229566	12/2019	CN	N/A
113928034	12/2021	CN	N/A
102017223600	12/2018	DE	N/A
3184180	12/2019	EP	N/A
20120090933	12/2011	KR	N/A
20120133671	12/2011	KR	N/A

OTHER PUBLICATIONS

Bjornsen et al. Plasma etching of different polydimethylsiloxane elastomers, effects from process parameters and elastomer composition, Elsevier, Microelectronic Engineering 87 (2010) 67-71 (Year: 2010). cited by examiner

Li et al. CN 111229566_English Machine Translation_Espacenet (Year: 2020). cited by examiner
European Search Report for European Patent Application No. 24180205.7 mailed Nov. 25, 2024. cited by applicant

Primary Examiner: Sosnowski; David E

Background/Summary

BACKGROUND

(1) Gas turbine engines, such as those that power modern commercial aircraft, include a fan section for propulsion, a compressor section to pressurize a supply of air from the fan section, a combustor section to burn a hydrocarbon fuel in the presence of the pressurized air, and a turbine section to extract energy from the resultant combustion gases in order to power the compressor and fan sections.

(2) The fan includes an array of fan blades that each have an aerodynamic surface contour. The blades may be formed from a composite, a metallic material, or combinations of these materials. A sheath is often secured to the leading edge of the blade to protect against impact from foreign debris injected into the engine. The blades may also have an erosion-resistant coating to protect the surfaces of the blade from being eroded from foreign debris.

SUMMARY

(3) A repair process according to an example of the present disclosure includes providing a gas turbine engine article that has an elastomeric coating that has an eroded region, plasma etching the elastomeric coating in the eroded region, and applying an elastomeric repair coating on the eroded region.

(4) In a further embodiment of any of the foregoing embodiments, the gas turbine engine article is a fan blade.

(5) In a further embodiment of any of the foregoing embodiments, the plasma etching partially removes a surface portion of the elastomeric coating to create a new bonding surface on which the elastomeric repair coating is applied.

(6) In a further embodiment of any of the foregoing embodiments, the elastomeric repair coating has an interfacial tensile strength with respect to the bonding surface of more than 1500 pounds per square inch (psi).

(7) In a further embodiment of any of the foregoing embodiments, the elastomeric coating is selected from the group consisting of silicone, urethane, fluoroelastomer, and combinations thereof.

(8) In a further embodiment of any of the foregoing embodiments, the plasma etching is conducted under an air, oxygen or argon plasma.

(9) In a further embodiment of any of the foregoing embodiments, the plasma etching is conducted for a time from 5 minutes to 60 minutes.

(10) In a further embodiment of any of the foregoing embodiments, the plasma etching is conducted for a time from 20 minutes to 60 minutes.

(11) In a further embodiment of any of the foregoing embodiments, the elastomeric repair coating on the eroded region is flush with the elastomeric coating adjacent the eroded region.

(12) A gas turbine engine article according to an example of the present disclosure includes a substrate, and an elastomeric coating disposed on the substrate. The elastomeric coating has a region in which a surface portion has been removed to create a bonding surface, and an elastomeric repair coating disposed on the bonding surface. The elastomeric repair coating has an interfacial tensile strength with respect to the bonding surface of more than 1500 pounds per square inch (psi).

(13) In a further embodiment of any of the foregoing embodiments, the substrate is an aluminum alloy.

(14) In a further embodiment of any of the foregoing embodiments, the elastomeric coating is

selected from the group consisting of silicone, urethane, fluoroelastomer, and combinations thereof.

(15) In a further embodiment of any of the foregoing embodiments, the elastomeric coating is fluoroelastomer and the elastomeric repair coating is silicone.

(16) The present disclosure may include any one or more of the individual features disclosed above and/or below alone or in any combination thereof.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The various features and advantages of the present disclosure will become apparent to those skilled in the art from the following detailed description. The drawings that accompany the detailed description can be briefly described as follows.

(2) FIG. 1 illustrates a gas turbine engine.

(3) FIG. 2 illustrates an article from the engine.

(4) FIG. 3 depicts a repair process using plasma etching.

(5) In this disclosure, like reference numerals designate like elements where appropriate and reference numerals with the addition of one-hundred or multiples thereof designate modified elements that are understood to incorporate the same features and benefits of the corresponding elements. Terms such as “first” and “second” used herein are to differentiate that there are two architecturally distinct components or features. Furthermore, the terms “first” and “second” are interchangeable in that a first component or feature could alternatively be termed as the second component or feature, and vice versa.

DETAILED DESCRIPTION

(6) FIG. 1 schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbopfan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. The fan section **22** includes a row of fan blades **23** that drive air along a bypass flow path B in a bypass duct defined within a housing **15** such as a fan case or nacelle, and also drives air along a core flow path C for compression and communication into the combustor section **26** then expansion through the turbine section **28**. Although depicted as a two-spool turbopfan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbopfans as the teachings may be applied to other types of turbine engines including three-spool architectures.

(7) The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

(8) The low speed spool **30** generally includes an inner shaft **40** that interconnects, a first (or low) pressure compressor **44** and a first (or low) pressure turbine **46**. The inner shaft **40** is connected to the fan section **22** through a speed change mechanism, which in exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive a fan section **22** at a lower speed than the low speed spool **30**. The high speed spool **32** includes an outer shaft **50** that interconnects a second (or high) pressure compressor **52** and a second (or high) pressure turbine **54**. A combustor **56** is arranged in the exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. A mid-turbine frame **57** of the engine static structure **36** may be arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The mid-turbine frame **57** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A

which is collinear with their longitudinal axes.

(9) The core airflow is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded through the high pressure turbine **54** and low pressure turbine **46**. The mid-turbine frame **57** includes airfoils **59** which are in the core airflow path C. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **48** may be varied. For example, gear system **48** may be located aft of the low pressure compressor, or aft of the combustor section **26** or even aft of turbine section **28**, and fan section **22** may be positioned forward or aft of the location of gear system **48**.

(10) The engine **20** in one example is a high-bypass geared aircraft engine. In a further example, the engine **20** bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), and can be less than or equal to about 18.0, or more narrowly can be less than or equal to 16.0. The geared architecture **48** is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3. The gear reduction ratio may be less than or equal to 4.0. The low pressure turbine **46** has a pressure ratio that is greater than about five. The low pressure turbine pressure ratio can be less than or equal to 13.0, or more narrowly less than or equal to 12.0. In one disclosed embodiment, the engine **20** bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor **44**, and the low pressure turbine **46** has a pressure ratio that is greater than about five 5:1. Low pressure turbine **46** pressure ratio is pressure measured prior to an inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. The geared architecture **48** may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1 and less than about 5:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present invention is applicable to other gas turbine engines including direct drive turbofans.

(11) A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet (10,668 meters). The flight condition of 0.8 Mach and 35,000 ft (10,668 meters), with the engine at its best fuel consumption—also known as “bucket cruise Thrust Specific Fuel Consumption (‘TSFC’)”—is the industry standard parameter of lbf of fuel being burned divided by lbf of thrust the engine produces at that minimum point. The engine parameters described above and those in this paragraph are measured at this condition unless otherwise specified. “Low fan pressure ratio” is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane (“FEGV”) system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45, or more narrowly greater than or equal to 1.25. “Low corrected fan tip speed” is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(T_{\text{am}} \text{ } ^\circ \text{R}) / (518.7^\circ \text{R})]^{\text{sup.}0.5}$. The “Low corrected fan tip speed” as disclosed herein according to one non-limiting embodiment is less than about 1150.0 ft/second (350.5 meters/second), and can be greater than or equal to 1000.0 ft/second (304.8 meters/second).

(12) FIG. 2 illustrates a representative one of the fan blades **23**. The blade **23** includes a root section **62** for attaching the blade **23** (gas turbine engine article), such as to a hub in the fan section **22**, and an airfoil section **64** that extends radially from the root section **62**. The airfoil section **64** defines leading and trailing edges **64a/64b**. In this example, a metallic sheath **65** is attached on the leading edge **64a** for protecting against foreign object impact. The blade **23** in this example is formed of an aluminum alloy, but may alternatively be formed of other alloys or composite materials. The remainder of the airfoil section **64**, including the sides and trailing edge **64b**, includes an elastomeric coating **66** that is disposed on the underlying aluminum alloy. A primer

layer (not shown) is applied onto the aluminum alloy to promote adhesion of the elastomeric coating **66**. The elastomer coating **66** is erosion resistant and protects the underlying alloy from being eroded by foreign objects (e.g., sand) ingested into the engine **20**. As an example, the elastomeric coating **66** is a silicone coating, a urethane coating, or a fluoroelastomer coating, but is not limited thereto.

(13) Although tough, the elastomeric coating **66** can be subject to damage from erosion over time. As the blades **23** in general are expensive to manufacture, it is desirable to be able to repair such damage rather than replace a damaged blade with a new blade. One strategy for repair is to abrade the coating, remove the damaged coating material, and then re-apply a primer as needed and a new surface coating. Such a repair, however, requires removing the eroded coating portion by grit-blasting or sanding, which can leave debris on the repair pre-bond surface, which in turn can debit adhesion and durability of the new repair coating. In this regard, FIG. **3** depicts a repair process that avoids grit-blasting or the like, while providing strong adhesion for good durability. It is to be appreciated that although the process is described with respect to the blade **23**, the process may be applied to other gas turbine engine articles that include such elastomeric coatings that require repair.

(14) A cross-section of a representative portion of the blade or other gas turbine engine article is shown at depiction (a). The blade **23** includes the aluminum alloy substrate **68**, a primer layer **70** on the substrate **68**, and the elastomeric coating **66** on the primer layer **70**. The elastomeric coating **66** includes an eroded region **72**. For example, the eroded region **72** is a region of the coating **66** which has been lost due to erosion, typically during use of the blade **23** in the engine **20** during service. As a result, the coating **66** is thinner at the eroded region **72** in comparison to the initial thickness of the coating **66**, shown by the dashed lines in the figure. Such erosion can occur from sand or other debris entrained in the air that flows across the blade **23**.

(15) As shown at depiction (b), the eroded region **72** is then subjected to a plasma etching treatment. Prior to treatment, the eroded region may be cleaned with a solvent, such as an acetone wipe or isopropanol wipe and, optionally, light abrasion. For example, the plasma etching is conducted under an oxygen, air or argon gas environment. The excited ions of the plasma bombards the surface of the eroded region of the coating **66**. Without wishing to be bound by any particular theory, the ions physically and chemically interact with the molecules at the surface of the coating **66**, thereby causing vaporization and oxidation (under oxygen or air) at the surface. Plasma etching may be used to clean surfaces. However, in this case, as the eroded region **72** likely contains embedded foreign debris, a relatively long process plasma etching process time is used to facilitate removal of a surface portion of the coating **66** and to activate the surface by oxidation to create a new bonding surface **66a**. For instance, a low pressure plasma etching is conducted for a time from 5 minutes to 60 minutes. Etching times toward the higher end of the range are used to ensure ample removal of debris and sufficient surface activation for better repair bonding, such as from 20 minutes to 60 minutes.

(16) Following the plasma etching, an elastomeric repair coating **74** is then applied on the new bonding surface **66a**. For instance, the elastomeric repair coating **74** is a urethane coating. The repair coating **74** may be applied as a liquid and then cured, such as in air and/or at an elevated temperature. In one example, the repair coating **74** is smoothed or otherwise molded such that the repair coating **74** is flush with the elastomeric coating **66** adjacent the eroded region **72** in order to maintain the aerodynamic surface profile of the blade **23**. The repair coating **74** can be a solid coating and a layer of adhesive may be applied on the plasma treated surface prior to applying the repair coating **74** and curing at room temperature or at an elevated temperature.

(17) Due to the removal of embedded debris and activation of the surface **66a**, the repair coating **74** forms a strong bond with the underlying coating **66**, even where the coating **66** is of a different type than the repair coating **74**. Thus, the repair coating **74** can be used on a variety of different types of original elastomeric coatings **66**, such as silicone, urethane, or fluoroelastomer. As an example, the

elastomeric repair coating **74** has an interfacial tensile strength with respect to the bonding surface **66a** of more than 1500 pounds per square inch (psi), as determined by a button pull off test (e.g., per ASTM D7234). In such as test, which may be simulated using test coupons, a button of known area is bonded to the repair coating **74**. The button is then pulled while measuring the pull force to determine a stress at which failure occurs. If the repair coating **74** is strongly bonded, failure will occur at other material layers or interface (e.g., the interface between the primer layer and the coating **66** or within primer layer) rather than the bonding interface between the repair coating **74** and the coating **66**. The maximum stress at which such failure occurs at another interface indicates that the strength at bonding interface between the repair coating **74** and the coating **66** is greater than that maximum stress. The following examples demonstrate additional aspects of the disclosure.

Example 1

(18) A repair was conducted in accordance with the description above in which a low pressure plasma etching was conducted in air under a plasma power of approximately 2 kW for 20 minutes. A urethane erosion coating was applied on the plasma treated repair surface and then cured at room temperature for 5 days. An aluminum button with an area of approximately 150 mm.^{sup.2} was then bonded to the repair coating using a paste epoxy. The button was then subjected to a pulling force at 150 psi/sec. Failure occurred within the primer or primer/erosion coating interface (not the interface between the repair coating and the original coating) at approximately 2750 psi.

Example 2

(19) A repair was conducted in accordance with the description above in which a low pressure plasma etching was conducted in argon for 5 min and air for 15 min under a plasma power of approximately 2 kW for 20 minutes. A urethane erosion coating was applied on the plasma treated repair surface and then cured at room temperature for 5 days. An aluminum button with an area of approximately 150 mm.^{sup.2} was then bonded to the repair coating using a paste epoxy. The button was then subjected to a pulling force at 150 psi/sec. Failure occurred within the primer or primer/erosion coating interface (not the interface between the repair coating and the original coating) at approximately 3000 psi.

Example 3

(20) A repair was conducted in accordance with the description above in which a low pressure plasma etching was conducted in air under a plasma power of approximately 2 kW for 40 minutes. A urethane erosion coating was applied on the plasma treated repair surface and then cured at room temperature for 5 days. An aluminum button with an area of approximately 150 mm.^{sup.2} was then bonded to the repair coating using a paste epoxy. The button was then subjected to a pulling force at 150 psi/sec. Failure occurred within the primer or primer/erosion coating interface (not the interface between the repair coating and the original coating) at approximately 3400 psi.

(21) Although a combination of features is shown in the illustrated examples, not all of them need to be combined to realize the benefits of various embodiments of this disclosure. In other words, a system designed according to an embodiment of this disclosure will not necessarily include all of the features shown in any one of the Figures or all of the portions schematically shown in the Figures. Moreover, selected features of one example embodiment may be combined with selected features of other example embodiments.

(22) The preceding description is exemplary rather than limiting in nature. Variations and modifications to the disclosed examples may become apparent to those skilled in the art that do not necessarily depart from this disclosure. The scope of legal protection given to this disclosure can only be determined by studying the following claims.

Claims

1. A repair process comprising: providing a gas turbine engine article that includes an aluminum alloy substrate and an elastomeric coating disposed on the aluminum alloy substrate, and the elastomeric coating has an eroded region; plasma etching the elastomeric coating in the eroded region, the plasma etching partially removing a surface portion of the elastomeric coating to create a new bonding surface on the elastomeric coating without removal of the elastomeric coating down to the aluminum alloy substrate; and applying an elastomeric repair coating on the new bonding surface.
 2. The repair process as recited in claim 1, wherein the gas turbine engine article is a fan blade.
 3. The repair process as recited in claim 1, wherein the elastomeric coating is selected from the group consisting of silicone, urethane, fluoroelastomer, and combinations thereof.
 4. The repair process as recited in claim 1, wherein the plasma etching is conducted under an air, oxygen or argon plasma.
 5. The repair process as recited in claim 4, wherein the plasma etching is conducted for a time from 5 minutes to 60 minutes.
 6. The repair process as recited in claim 1, wherein the plasma etching is conducted for a time from 20 minutes to 60 minutes.
 7. The repair process as recited in claim 1, wherein the elastomeric repair coating on the eroded region is flush with the elastomeric coating adjacent the eroded region.
 8. The repair process as recited in claim 1, wherein the elastomeric repair coating has an interfacial tensile strength with respect to the bonding surface of 1500 pounds per square inch (psi) up to approximately 3400 psi.
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