Progress in Organic Coatings 105 (2017) 190–199

Contents lists available at ScienceDirect

Progress in Organic Coatings

journal homepage: www.elsevier.com/locate/porgcoat

Performance evaluation of polybenzimidazole coating for aerospace application

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ARTICLE INFO

Article history:
Received 18 May 2016
Received in revised form 9 November 2016
Accepted 11 January 2017

Keywords:
Polymer composites
Polybenzimidazole coating
Adhesion testing
Environmental conditioning
Scratch test
Nano-indentation

ABSTRACT

In Present study, characteristic behavior of PBI as a protective coating for aircraft application is presented. Performance of PBI coating is evaluated after exposure to hot wet environment and liquid immersion. Critical properties including hardness, scratch resistance and adhesion of PBI coating are assessed and results are presented. M21 epoxy based carbon fiber composite is used as substrate material. Atmospheric pressure plasma treatment (APPT) is performed to prepare the surface of substrate prior to application of PBI coating. Lap shear tests demonstrate that APPT has improved the adhesion strength of PBI bonded joints to about 250%. SEM analysis shows that strong composite/coating interface resulted in cohesive failure of the bonded joints. Lap shear test results on conditioned samples reveal that composite bonded joints has depicted about 15% decrease in strength after exposure to hot/wet environment under the conditions of 80 °C and 95% relative humidity (RH). However, mode of failure of bonded joints has not changed even after 1000 h of conditioning. PBI coated samples were also immersed in water and Skydrol to evaluate the effect on hardness and scratch resistance of PBI coating. Scratch tests on conditioned samples reveal that the visco-elastic recovery has increased from 58% (unexposed sample) to 71% with PBI coated panel immersed in skydrol. However, no major effect on visco-elastic recovery is observed with the samples immersed in water and the sample conditioned in hot/wet environment. Nano-indentation test results indicate that PBI coated panel immersed in skydrol has not depicted any decrease in elastic modulus ad hardness; whereas coated panel immersed in water for 1000 h has shown a minor decrease in both modulus and hardness. All these results indicate that PBI coating has great potential to retain its properties under harsh environment and it can be used as protective coating for aerospace application.

1. Introduction

Polymer based composite materials are gaining wide attraction for aerospace applications due to their high specific strength and stiffness, excellent corrosion resistance, outstanding thermal insulation and low thermal expansion. Under flight service environment of aircraft, composite materials are exposed to different environmental conditions of temperature, humidity, particle erosion and ultraviolet radiations [1]. All these conditions play a part in minimizing the integrity of composites. Most of the properties of composite materials are matrix dependent and matrix resins are more sensitive to above mentioned environmental conditions. Durability of composite materials can be improved by applying a high performance coating material which can protect these materials from flight service environment. Currently, different multi-component protective coatings are being used for the protection of composites used in aerospace applications. The coating systems currently used for the protection consist of an epoxy primer and a polyurethane top coat [2]. Most of the times, an intermediate coat is also applied to get some desired function. More than one component is required to achieve the desired functions from a coating system. The total dry thickness of the multi-coat system ranges between 200–380 μm [2]. Application of using two to three different coats to get the desired performance, ultimately, increase the time of application and add considerable weight to the aircraft. Also, some pigments and additives are added to these coatings to improve their performance against environmental service conditions. Addition of pigments in the coating material causes the problem of chalking which ultimately affect the performance of the coating material [3].

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http://dx.doi.org/10.1016/j.porgcoat.2017.01.005
0300-9440/

Based on the above discussion, the objective of current work is to develop a coating material which can be applied directly to the composite substrate without using any primer and it should also perform the desired functionality. Elimination of the primer coat will help to reduce the application time and weight which in turn can save the cost of material, manpower and in flight service cost. Furthermore, problem of chalking can also be resolved by using a coating having no pigments. In this context, Polybenzimidazole (PBI) coating will be tested and evaluated for its performance after exposure to various environmental conditions. PBI is recently emerged high performance thermoplastic coating which has the highest glass transition temperature Tg (425 °C) and highest tensile strength of 160 MPa [4–6]. Due to its high thermo-mechanical properties and environmental resistance, it has great potential to be used as a protective coating for aircraft in hot/wet environment. Critical properties including hardness, scratch resistance and adhesion of PBI coating after exposure to various environmental conditions will be evaluated. Based on the properties of PBI, it is expected that the coating will protect the composite material from hot/wet environment and help them to retain their mechanical properties for longer period of time.

2. Experimental

2.1. Materials

26% concentrated solution of Polybenzimidazole (PBI) in Dimethyleacetamide (DMAc) was supplied by CELAZOLE, PBI performance products. M21 epoxy based unidirectional (UD) carbon fiber prepreg were supplied by Hexcel. M21/carbon epoxy composite laminate was manufactured using 16 prepreg plies laid up in unidirectional configuration to make a total thickness of 4 mm. The laminate was cured in an autoclave at 180 °C under a pressure of 0.68 MPa.

2.2. Sample preparation

2.2.1. Atmospheric pressure plasma treatment of composite substrate

In this investigation, Composite surfaces were treated with atmospheric pressure plasma jet using TIGRES Plasma-BLASTER MEF equipment. Air was used as a gas with a total flow rate of 51 l/min. The equipment was operated using compressed air at a pressure of 4.5 bar using a power of 400 W. The treatment distance of substrate from nozzle head of plasma equipment was 20 mm. Before performing the plasma treatment, the samples were first cleaned with acetone using an ultrasonic bath to remove any contamination on the surface. After cleaning, the specimens were dried in a vacuum oven at 80 °C for 4 h followed by the plasma treatment of the samples for 45 s.

2.2.2. Contact angle measurements

The change in wetting properties after plasma treatment and hand sanding treatment was determined in terms of contact angle using water as a liquid. A reduced value of contact angle indicates an improvement in wetting and adhesion properties of materials. Contact angle measurements were carried out by the Modular CAM 200–Optical Contact Angle and Surface Tension Meter from KSV Instruments. Samples of 30 mm × 30 mm were cut, cleaned with acetone and plasma treated using aforementioned conditions. 5 μl of water volume was used to take the contact angle measurements. 3 reading were taken for each sample and average values are presented with standard deviation.

2.2.3. Application of coating

The as-received 26% concentrated solution of PBI in DMAc was highly viscous and therefore it was essential to dilute the solution for proper processing. DMAc was added to the PBI solution to dilute the solution down to 17%. The solution was stirred mechanically at 60 °C for 15 min to get a uniform mixture of PBI in DMAc. The mixture was then used as a coating for composite laminate to produce a coating thickness of about 100–120 μm. Metering Doctors blade was used to maintain uniform thickness of the coating. The coating was allowed to dry in the vacuum oven at 80 °C for 2 h. Afterwards, the coated samples were further dried in vacuum oven at 125 °C for overnight. After coating was completed, it was observed that the standard deviation of the coatings was around 7 μm.

2.3. Exposure of PBI coating to various environmental conditions

2.3.1. Conditioning of PBI coated panels at high temperature and humidity

Coated panels were prepared and exposed to high temperature and humidity environment. The purpose was to evaluate the influence of temperature and humidity on the coating performance. Coated coupons of 30 mm by 30 mm were prepared and conditioned at 80 °C with a 95% relative humidity (RH) for 1000 h. Resistance of PBI coating to hot-wet environment was evaluated through scratch test and nano-indentation test.

2.3.2. Liquid immersion of PBI coated panels

Resistance of the coating to water and Skydrol is also examined by full immersion test. Skydrol is a harsh solvent used in aerospace industry. Therefore coating resistance is examined against this solvent. Coated coupons of 30 mm by 30 mm were immersed in water and Skydrol for 1000 h at ambient conditions. After 1000 h, the panels were visually inspected for any sign of blistering or delamination. Resistance of the coating was evaluated through scratch test and nano-indentation test.

3. Testing and characterization of conditioned PBI coated panels

3.1. Adhesion testing of unconditioned PBI using lap shear test

For this particular study, lap shear test is used in order to determine the adhesion properties of PBI. Lap shear test provides both quantitative as well as qualitative information about coating adhesion. Single lap shear joints of carbon/epoxy composite were prepared with an overlap length of 12 mm × 25 mm. Joints with both untreated surfaces and atmospheric pressure plasma treated surfaces were prepared in order to study the effect of surface treatment on adhesion properties of PBI.

3.2. Adhesion testing of conditioned samples

Coating adhesion was evaluated both before and after exposure to hot-wet environment using lap shear test. The purpose was to evaluate the influence of temperature and humidity on the PBI bonded joint strength. Joints were conditioned in a climate chamber for 1000 h at 80 °C and 95% relative humidity.

3.3. Scratch testing of conditioned PBI coated panels

Scratch tests on unexposed PBI coated panels and the panels exposed to various environmental conditions were performed. The purpose was to evaluate the scratch resistance of PBI coating after having exposed to different environmental conditions. Scratch test is a quantitative technique in which critical loads are used to compare the cohesive or adhesive properties of coating material. Critical