A Case Study on Damage Detection of Wind turbine Composite Blade

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In the entire wind turbine the most important part is the blade, which decides the power output by the virtue of size and shape. The design and material selection of a blade is very crucial since it constitutes the 20% of the total manufacturing cost of a whole wind turbine. To be specific, the blade material selection, manufacturing process, inspection and repair are very crucial in deciding the performance and life of the blade. Here we report the damage detection after manufacturing of turbine blade especially joints on the assembled blades by using latest techniques like infrared and ultrasonic inspection. The turbine blade is made up of glass reinforced plastic composite material manufactured by resin transfer moulding process with a length measuring up to 35.7 m. The infrared inspection method involves recording the variances in surface temperature due to heat generated by adhesive curing along bond lines. Using infrared images the type of defects like lack of adhesive webs, glue voids and uncured bonds are identified. Further inspection of adhesive joints between the blade shell and main webs and detection of its size is also carried out using ultrasonic B-scan method. The improper placing of web or hand lay-up laminate repair with improper bonding resulted signal loss. The defect thermographs and ultrasonic test scans of defects are also shown to show the accurate identification of the defects after manufacturing of a turbine blade. Finally the defects like dry laminate, delamination and wrinkles identified in the turbine blade are repaired following the appropriate methods and standards.

Keywords: *Wind turbine blades, Composite materials, Inspection, Non-destructive testing, Structural repair.*

1. INTRODUCTION

Serious issues have been raised by environmentalists due to rapid raise in air pollution because of usage of fossil fuel across the world. In order to decrease the dependency of fossil fuel and reduce the emission of greenhouse gases, the focus is on electrical power gene–ration from wind energy. Wind energy has emerged one of the prominent sources of renewable energy which converts the kinetic energy available in wind into mechanical or electrical energy. This technology has gained important role and has an edge over other renewable energy sources as it is pollution free tech–nology, technological maturity and cost competit–iveness. The emerging markets like China and India have led an increase in the annual installations of wind power capacity of 63.46 GW in the year 2015. However the success of wind technology depends on cost of wind turbine system, average wind speed and wind distri–bution in that region [1-4]. In their work, Rasuo et al. [5,6] used genetic algorithm to wind farm layout design for optimum placement of wind turbines to get sufficient amount of wind speed so that they will operate and produce required energy.

The reliability of wind turbine system mainly de–pends upon its critical parts or components which are designed and fabricated to perform under specific envi–ronmental conditions. The performance will be affected due to poor reliability and will result in increase in maintenance cost and subsequent decrease in lifetime of a turbine system. These wind turbines operate under harsh environmental conditions like UV rays, thermal stress, lightening, moisture absorption and wind speed gusts subject the different wind turbine components to various problems [7,8]. Out of all components, the most common damage that occurs in a wind turbine system is failure of blades. The blade experiences different types of aerodynamic loads, impact and fatigue events while in operation which can eventually lead to blade failure. In addition to this a failed blade not only damages the other blades but also the whole wind turbine itself. As the blade is one of the key component and cost up to 15-20% of total cost of a wind turbine system [9-11]. Studies have shown that mean time between failures of blade is of the order of ~12 years which is almost 40% less that of design life of about 20 years [12]. Here not only the maintenance and repair cost is very expensive but also needs considerable time to repair. Due to aforementioned reasons utmost care and extensive attention has to be given to the monitoring of the wind

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turbine blades. Further with the increase in numbers of operating utility grade turbines, blade reliability will become more critical [9,13,14]. Along with this many st

Most of the present turbine blades are manufactured using composite materials. The advantage of using composite material based blade it combines the toughness of matrix and strength of reinforcement which is not possible by conventional monolithic metals or alloys. The composite blades are generally manufactured by techniques like, Wet hand layup, filament winding, resin infusion and prepeg [15,16]. Kong et al. [17] developed E-glass/epoxy composite for medium scale wind turbine blade of a horizontal axis wind turbine of 750 kW capacity. The E-glass/epoxy composite was chosen because of its low cost, required specific stiffness and strength and manufacturing feasibility. The blade was manufactured using lay-up method in which GFRP fabric prepregs were laid on master mould with appropriate stiffeners. In order to avoid moisture penetration and solar deterioration, a special gel coat was applied to the blade. Full scale structural tests were carried out to simulate the aerodynamic loads at different locations from the blade root. These tests are necessary to obtain structural integrity of the blade. Manufacturing of the wind turbine blades often comprised of many manufacturing defects which can have an adverse effect on strength and service life. The defects formed are porosity, fiber waviness, bonding defects, foreign inclusions and wrinkles. Apart from the manufacturing defects the blades can fail during operation due to adhesive joint failure, buckling induced skin debonding, sandwich debonding, skin debonding and cracks in gelcoat. These defects are generally detected by non-destructive technqiues like acoustic emission, X-ray or using ultrasound [18-22].

In order to achieve a smooth and continuous operation of wind turbine, structural health monitoring of wind turbine system, especially blades has grown considerably in last few years. In this regard, blade reliability is broken into specific tasks which include blade defect and repair survey, inspection validation, analysis evaluation and certification testing. Aforementioned reasons have led to lot of research work in finding out different types of inspection techniques to detect the damages during/after manufacturing process and while during operation. After manufacturing the blades are subjected to non-destructive testing methods like, visual inspection, ultrasonic testing, tap test and thermography. The most promising methods for damage detection are acoustic emission, impendence based, wave propagation and vibration based methods. This allows real time monitoring of blades in order to predict the early failure and validate the comprehensive performance [23-25].

In the present we have conducted the two different inspection techniques to reveal the various defects on 35.7 m long glass reinforced plastic composite blade. The blade was subjected to infrared thermography and ultrasonic testing to reveal the various defects and there location in adhesive joints like spot curing glue, dry glass, glue void and uncured bond. This work was conducted with sole attention to address the severe challenged faced by wind turbine industry. The structural repair process in aerospace industry are well developed with many updated techniques however the same effort is needed in wind turbine industry. As mentioned earlier the damage detection and repair at early stages not only save the money but as well as also give an insight to avoid the manufacturing defects. Along with this the wind turbine industry can be more affordable since other non-renewable energy sources are headed towards depletion.

2. EXPERIMENTATION

The blade was made up of glass reinforced plastic composite material manufactured by resin transfer moulding process with a length measuring up to 35.7 m. The main objectives of the experimentation are to conduct ins– pection of adhesive joints using thermography and ultrasonic testing of performance evaluation of glass reinforced plastic composite blades.

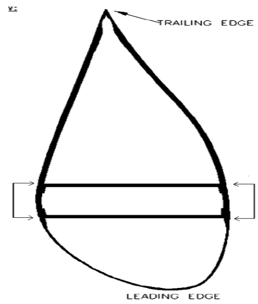


Figure 1. Main areas of the blade to be inspected

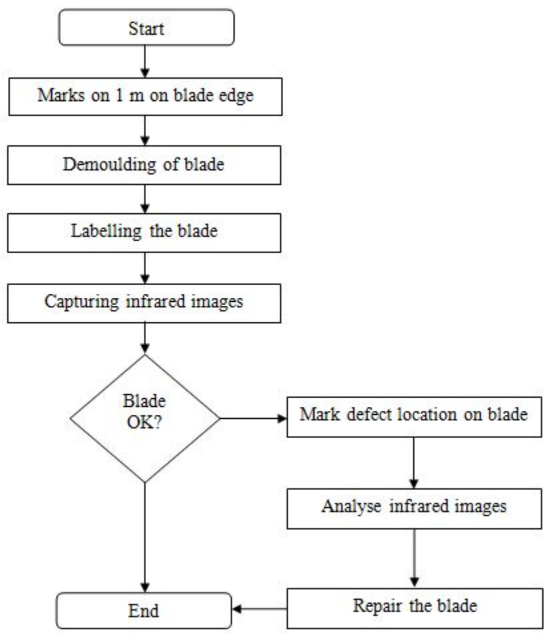


Figure 2. Flowchart for infrared thermography.

To inspect the critical area like adhesive joints, we have conducted infrared thermography using infrared Camera (Make: FLIR ThermaCAM P 65) to examine the whole length of the blade. For infrared camera FLIR T197189 Wide Angle Lens was used and for report generation software called ThermaCAM Reporter was used. Fig. 1 shows the inspection locations, web shield against upwind shell and downwind shell, leading and trailing edge. A simple flowchart is shown in Fig. 2 which describes briefly the infrared thermography being carried out. Here the inspection is done as soon as the blade de-moulding is done. The blades are marked on the blade edges at 1 meter intervals (as shown in Fig. 3a) and ensure the accurate reference points, numbers are placed. In addition to this measuring tape is located at the each meter markings on the blade edges from root to tip of the blade. Once it is done, the blade is placed with the trailing edge pointing upwards that is about 90° perpendicular to the floor as shown in Fig. 3b. The images from infrared camera are taken while there is much heat in the bond lines; this is mainly because to verify the glue curing properly and the infrared images obtained are good and clear. The optimal temperature difference between the main laminate area and web should be ≥2°C. For image, the infrared camera is focussed with the camera level and span adjusted correctly covering approximately 1.5 m of the blade length and perpendicular to the blade surface. Once the images are taken, all the potential defects on the blades are marked.

(a) (b)

Figure 3. (a) Reference marking at 1 meter interval and (b) Placing the blade with trailing edge upwards.

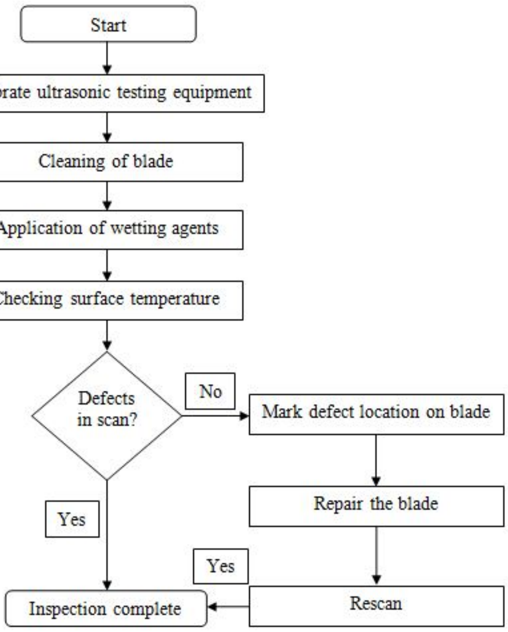


Figure 4. Flowchart for ultrasonic testing.

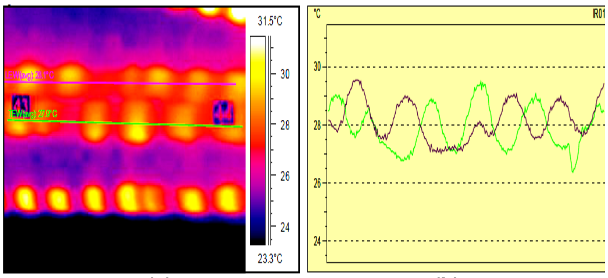
The second objective of the work is to carry out the ultrasonic inspection of glass reinforced plastic. A simple flowchart is shown in Fig. 4 which describes briefly about the infrared thermography being carried out. The purpose of conducting this inspection is to check the performance requirements and to check if there is any conflict between the specification and manufacturing documentation. The performance evalu–ation of the blade using ultrasonic examination is done according to the ASTM standards, ASTM E317 and ASTM E1316 without the use of any electronic instru–ments. The inspection is carried out in a non-freezing environment, with blade surface free from any dust or any other foreign contaminant which can interfere with the coupling. For this purpose, Olympus OmniScan was used to perform inspection procedures while for measuring ultrasonic response from any sort of discontinuity, a circular transducer with an active ele–ment of 25.4 mm diameter and a frequency of 0.5 MHz was used. The same scanner is used for initial scanning and evaluation of any other discontinuity. The couplant material like water with or without liquid soap is applied between the transducer and test surface is used to permit transmission of acoustic energy. In order to avoid large attenuation and velocity differences in wedge materials, the surface temperature should be within ±3°C during the calibration and inspection period. Usually an infrared thermometer is used to measure the surface temperature.

The final and important step in the work was to repair the damages occurred while manufacturing. So repair of glass reinforced plastic composite involved following steps: grinding of defect area, measuring the repair, cut the glass according to dimensions required, lay up glass and resin, curing and finishing. The entire repair process where conducted by maintaining a minimum of 18°C air and blade temperatures. The relative humidity in air was also maintained well within 80%, but for cold curing the relative humidity in air was not allowed to exceed 90%.

3. RESULTS AND DISCUSSION

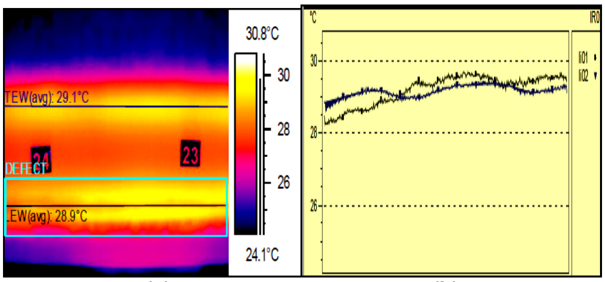
3.1 Inspection process

The adhesive joints between the main webs and blade upwind and downwind shells are very critical points in the blade structure. It is necessary that these parts need particular care so as to identify any flaws present. By taking the infrared images, the flaws detected at this stage can be repaired easily. Taking the advantage of variances in surface temperatures from the heat generated by adhesive curing along the bond lines, 100% detection of defects induced during manufac–turing process is possi–ble [26,27]. Figs. 5 to 8 are the thermographs and corres–ponding temperature variance of the various sections of the blade taken during inspection of adhesive joint. When we observed the Fig. 5a, there is clear visual image of the defect in that section of the blade which was caused due to irregular distribution of adhesive initiator during adhesive application process. The presence of defect is well supported by significant change in the temperature between the bond lines which is shown in Fig. 5b. As shown in Fig. 6a, the visual of dry glass defect is clearly visible which in turn doesn't show any abnormal change in the temperature between the two bond lines (See Fig. 6b). The thermograph shown in Fig 7a is of presence of glue void between the two sections 18 and 19. The void is visible as a discontinuity which is indicated as change in colour. The presence of void is well supported by the drop in temperature value at that particular spot as shown in Fig. 7b. Finally the final defect observed was wet glue or uncured bond. Fig. 8a shows the discontinuity in the colour coding in between sections 37 and 38. The pre–sence of the wet glue reflected in the significant change in the temperature between the two bond lines which is shown in Fig. 8b. Like this the defects observed at each section are noted down and are repaired at this stage by making use of thermographs obtained [28,29]. In a similar work, Rasuo [30] conducted the inspection of helicopter rotor blade using acoustic emission and infra–red thermography to check delamination or permanent deformation before and after fatigue tests.



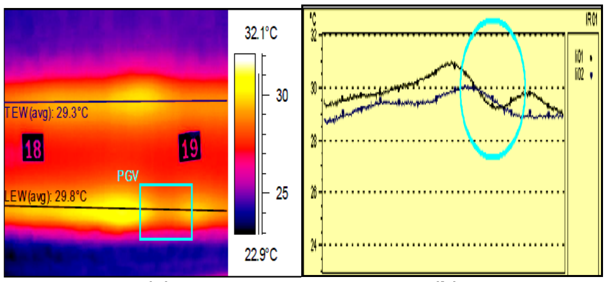
(a) (b)

Figure 5. Inspection of adhesive joint showing, (a) Infrared image of spot curing glue defect and (b) bar graph showing temperature variance.



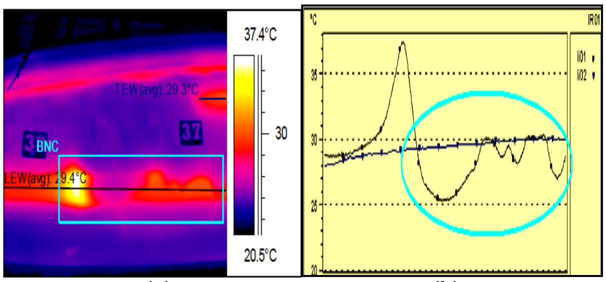
(a) (b)

Figure 6. Inspection of adhesive joint showing, (a) Infrared image of dry glass defect and (b) bar graph showing temperature variance.



(a) (b)

Figure 7. Inspection of adhesive joint showing, (a) Infrared image of glue void and (b) bar graph showing temperature variance along bond line.



(a) (b)

Figure 8. Inspection of adhesive joint showing, (a) Infrared image of uncured bond and (b) bar graph showing temperature variance along bond line.

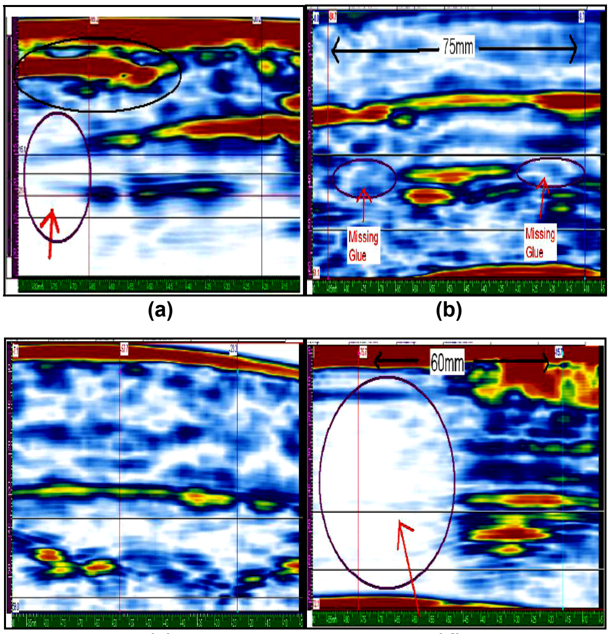
In next stage of inspection we have performed ultrasonic testing of adhesive joints between main webs and blade shell. Here both the upwind and downwind blade shells are inspected along entire length to check the web bond lines. The principle of ultrasonic testing is when ultrasonic waves are transmitted into the composite material the internal defects like disbanding or delamination influence the wave propagation resul–ting in local change [31,32]. Fig. 9a - d shows the scanned images of various defects found in the glass reinforced plastic composite blade. Fig. 9a shows the scanned image of particular section of blade displaying improper placement of web. The web was not placed in proper position or it might have shifted the position while fabri–cation process. So we can see from the image that there is a loss of signal due absorption of signal by balsa wood (shown by red arrow mark). The loss of signal was mainly due to resting of web over the blade shell balsa in the laminate. We can see the laminate signal above the balsa wood on the left side of the scans but there is no true signal below it. In case of Fig. 9b, we can observe that the case of narrow bond, glue missing which was needed to bond blade shell. The missing glue is shown by red arrow marks in the scanned image. The minimum required length in this area is 75 mm, but when we observe the scan carefully we can find that their is no glue bonded to either web flange or blade shells to meet the 75 mm length requirement. Fig. 9c, this scanned image shows the wet glue which was earlier detected in infrared image and then reconfirmed with the ultrasonic testing. The loss of signal in this particular scan is the indication of presence of wet glue. Finally the Fig. 9d, the dry glass defect is seen in the joint area. The loss of signal caused by the dry glass is seen in the scanned image. When such defects are seen during inspection, the pro–cedure is to rescan the defect locations again. Such defect area are marked on the blade shell and subjected to repair.

3.2 Repair process

Once the defect area and size is obtained by infrared thermography and ultrasonic testing, the blade is taken for repair purpose. The repair in conducted in controlled temperature and relative humidity such that the surro–unding environmental conditions doesn’t obstruct the repair work as well as lead in to new defects. The photographs of defects like dry laminate and wrinkles formed due to fibre orientation out of plane either nega-tively or positively identified are shown in Fig. 10a & b. The repair process of the damaged area as shown in Fig. 10 is done by following the steps as given below [33,34].

Grinding and chamfering: The defects identified are subjected to grinding using grinder which removes all the damaged laminate. It is necessary to remove the dry glass at glass fibre pultrusion pieces or triangles and then gro–und off. This is followed by chamfering of damage in which grinding the chamfers in the rectangular shape is done as shown in Fig. 11a. The chamfering is done in such a way that it should be even and the deviation sho–uld not be greater than 1 mm. The surface as mentioned should be even and checked using 300 mm surface plate or a steel ruler. If the surface is not even than it has to undergo re-grinding for smoothness.

Cutting of glass and application of resin: According to the dimension of the damaged area the glass is cut according to required specifications. This is followed by application of layer of resin on the damaged and chamfered area as shown in Fig. 11b.

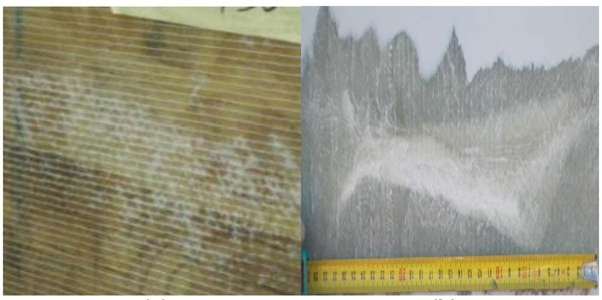


(a) (b) (c) (d)

Figure 9. Ultrasonic inspection of adhesive joints between main webs and blade shell showing (a) Improper placement of web, (b) narrow bond, (c) wet glue and (d) dry glass

Curing and finishing: Once the resin is applied on the chamfered area, the repair laminate is placed and a hard roller is used to rollout each layer as shown in Fig. 11c. It is necessary that the initially a large layer is applied first and made sure that repair laminate is smooth and in proper level with the surrounding laminate. Here the hard rolling is done on each and every ply to remove any entrapped air from the laminate and made sure that air bubbles are visible from the wet ply. The rolling must also be consistent in order to ensure that the resin should not gel before the last ply is hard rolled.

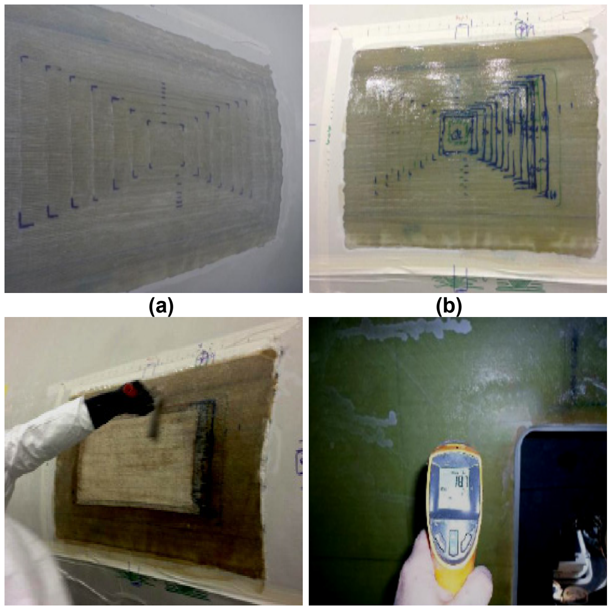
Temperature measurements: It is necessary that the humidity and temperature before and after lamination process is measured as shown in Fig. 11d. The usage of heat blanket or insulation helps to reduce the hardening time and to control the surface temperature well within the prescribed temperature of 75°C.



(a) (b)

Figure 10. Photographs of defects identified by inspection process are (a) dry laminate and (b) wrinkle formation due to fibre disorientation.

As mentioned above, the repair procedures are followed correctly to ensure no defects are left being addressed. In a similar work, Dinulovic et al [35] used 3D random fiber composites as a repair material for a damaged honeycomb sandwich panel. Here the repair process entirely depends how the defect can be closed, whether by same material as that of blade or other. It is better to choose the same material as that used for making blades.



(a) (b) (c) (d)

Figure 11. Repair process involving, (a) grinding and chamfering of damaged area, (b) application of resin layer, (c) hard roller to roll out each layer and remove excess resin and (d) temperature measurements before and after repair.

4. CONCLUSION

Owing to its huge commercial importance and affordability, in present work we have shown the cost effective defect identification and repair techniques. For this a turbine blade made up of glass reinforced plastic composite material of a length measuring up to 35.7 m was fabricated. This modern type of composite blade is designed aerodynamically with load carrying spar with adhesively bonded upwind and downwind blade shells. The various manufacturing defects like dry glass, wet glue, narrow bond and uncured bond were identified using latest technologies like infrared thermography and ultrasonic testing after the manufacturing of the blade. Identification of defects along with their size and location was revealed by these two inspection technologies. The identified defective areas subjected to structural repair process. The repair process involves, grinding, chamfering, curing and finishing following the standard procedures. After repair process the area was scanned once again and found ok which is very much necessary for smooth operation of wind turbine blades.

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СТУДИЈА СЛУЧАЈА ДЕТЕКЦИЈЕ ОШТЕЋЕЊА ВЕТРОТУРБИНЕ СА ЛОПАТИЦОМ ОД КОМПОЗИТНОГ МАТЕРИЈАЛА

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Лопатица је најважнији део ветротурбине јер одређује излазну снагу својим габаритом и обликом. Пројектовање и избор материјала су од значаја зато што 20% трошкова изградње турбине отпада на ова два параметра. Тачније, избор материјала за израду лопатице, процес производње, инспекција и поправке играју важну улогу у перформансама и радном веку лопатице. У раду се приказује детекција оштећења на спојевима код лопатице применом најновијих техника инфрацрвених зрака и ултразвука. Лопатица је израђена од композита у којем је матрица ојачана стакленим влакнима са скрућеном смолом. Дужина лопатице је 35,7 м. Методом инспекције инфрацрвеним зрацима региструју се све промене површинске температуре узроковане топлотом коју генерише материјал за лепљење шавова. Коришћењем инфрацрвених зрака идентификовани су дефекти као што су одсуство преграда, шупљине у лепку и незалепљени спојеви. Даља инспекција лепљених спојева између омотача лопатице и главних преграда и детекција величине дефекта извршена је коришћењем ултразвучне методе Б-скенирања. Неправилно постављање преграда или ручна поправка ламинацијом неадекватним спајањем доводи до губљења сигнала. Такође су приказани дефекти откривени термографима и скенирањем ултразвуком, што је допринело прецизној идентификацији дефеката после изградње лопатица ветротурбине. Најзад, дефекти као што су ламинација, деламинација и борање детектовани код лопатице турбине су поправљени применом одговарајућих метода и стандарда.