A STUDY ON REPAIRING PROCEDURES INVOLVED WITH LEADING EDGE CRACKS, OFFSETTING, OVERBITE & UNDERBITE OF GLASS FABRIC REINFORCED COMPOSITE BASED WIND TURBINE BLADES

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ABSTRACT

Rotor blades are the most important part of wind turbine system, which are generally made up of polymer matrix based composites. The performance and lifetime of the wind turbine system often depend of the constituent of composite materials, properties of these materials, design of blades and manufacturing techniques. However the inspections after manufacturing of blades do reveal certain defects which need to addressed and fixed before it is sent for real time operations. Further offsetting usually occurs when closure of two blade halves lead to displacement of aerodynamic suction side from the aerodynamic pressure side. This work is concerned with the two main objectives: one is to repair leading edge cracks in the longitudinal direction, outside the area with existing external root over lamination, the second objective is to how offsetting is measured, evaluated and repaired especially in connection with: overbite and underbite. All these repair procedures were conducted on the glass fabric reinforced polyester blades manufactured by Hand lay-up technique. Until aforementioned repair procedures are not performed, the blades will not be sent to assembly stage. Ultrasonic inspection was conducted as per ASTM standards, ASTM E317 and ASTM E1316.

Keywords: Turbine blade, Glass fabrics, Composite Materials, Manufacturing process, Structural repairs.

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1. INTRODUCTION

Due to rising levels of greenhouse gases and depleting fossil fuels have led to intense research and development in the field of renewable energy sources. In order to combat these global issues many renewable energy sources like solar, tidal, biomass and wind energy are being tried out in small as well as large scale and to meet increasing energy needs. Many European countries are opting for renewable energy resources for various energy needs which not only help in preserving the environment but also contribute in economic and social success [1]. Out of all energy sources, conversion of wind energy into other useful form of energy has gained a lot of momentum as a renewable energy source. The basic principle of energy production is conversion of kinetic energy of wind to electrical energy by means of wind turbines. Choosing wind energy over other energy sources is mainly because it is available everywhere, clean, renewable and most important no greenhouse gas emissions. Along with this the power generation cost using wind energy is relatively low when compared to that of other renewable energy sources. The recent developments in wind turbine technology have maximized the interaction of wind turbine blades with air to gain maximum efficiency [2,3]. According to statistical projection by Global Wind Energy Council (GWEC) the wind energy is capable of fulfilling about 12% of total electricity demand worldwide by the end of year 2020. On the other hand European Wind Energy Association (EWEA) is working towards increasing the wind capacities by a factor of 6 by 2030. In addition to this in developing Asian countries like India and China the electricity production using wind energy will increase rapidly in next decade [4-6].

Out of all, the blades are the most critical and important components of a wind turbine as they are the one which collects the wind energy. By means of aerodynamically designed blades, a wind turbine extracts the power from the wind and converts it into mechanical or electrical energy [7]. Generally a wind turbine can have any number of blades but keeping centrifugal forces in mind most of them are restricted to three blades. Though the increase in number of blades can help in improving the aerodynamic efficiency but it will increase the mass on the turbine as well as the material cost for these blades. This increase in material cost will outweigh the beneficial effect obtained from increased number of blades. Wind turbine blades are subjected to various loads like static, fatigue or installation loads under severe working conditions of moisture, temperature, lightning strike, erosion or bird strike [8-10]. Even a simple minor damage on the blade during working conditions can lead to serious secondary damage to the whole turbine due to rotating mass unbalance. The most important design considerations for blades are aerodynamic performance, blade materials, blade manufacturing, structural strength, blade roots and overall costs. As mentioned earlier that the blades are most important components because they can cost up to 20% of overall cost of the wind turbine. So it is necessary that these blades should be designed properly and manufactured with materials possessing adequate structural properties. But it should be also ensured that the materials and manufacturing techniques used for blades should be of low costs after ensuring the required properties are not compromised. Keeping this is in mind, wet lay-up and vacuum assisted resin transfer moulding are the most widely used blade manufacturing techniques [11]. However whatever might be the manufacturing techniques the problems starts with the increase in size of the blade. As the blade size increases, tolerances increases which cause variation in the thickness of the adhesive bond which eventually lead to weight gain. Along with this the defects become more severe in large blades resulting in lower strength. Many works have suggested separate fabrication of large parts of blades and later joining them with adhesive bonds. This is due to fact that the individual pieces are easy to fabricate with better quality and minimal defects. Choosing the right manufacturing technique will ensure to overcome these drawbacks and will help in the reduction in production costs of the blades. Further it will be more beneficial and cost effective with respect to their periodic maintenance and replacement point of view [12,13]. In their review article, Veers et al. [14] summarised the recent on-going trends in the commercial wind turbine blade design, manufacture and testing. Various important topics like improved blade design criteria, new blade design, optimal use of carbon and carbon hybrid materials, effect of aerofoil thickness on structural efficiency were discussed.

Most of the wind turbine blades are made up of various materials like wood, aluminium alloy and steel beam with glass fibre envelope. But due raising demand for electricity, the wind turbine manufacturers are forced to develop new materials and manufacturing techniques for blades. Owing to these many problems, most of the blades manufacturers are increasing the size of rotor diameters up to 180 m with obtain power output as high as 9.5 MW. However increasing the rotor diameters is not the only solution to the problems because it will result in high costs mainly due to production, handling and maintenance of the rotors. So with the growing size of rotors, it is necessary to have blade which can be manufactured with the materials which are very light in weight, have high rigidity, high strength and corrosion resistant. Here the high stiffness of the material will help in maintaining the aerodynamic performance while its low density will reduce the effect of gravity forces [15]. In this regard composite materials based upon glass fibre, carbon fibre or wood in epoxy, polyester and vinyl ester matrices are used extensively for manufacturing of blade. The judicious choice of matrix and fibres allows design engineer to tailor the properties depending on the application. Carbon fibres possess high strength (~4000 MPa) and stiffness (~2-4 GPa) but are very expensive than other fibrous materials. In addition to this nanocomposites based on carbon nanotubes are also being projected as probable candidate materials for wind turbine blades [16-21]. The glass fibre is the most sought reinforcement material for the composite materials mainly due to cost when compared to that of carbon fibres [22]. The glass fibres are also having good properties such as tensile strength of 3500 MPa and elastic modulus of 220-240 MPa. But the recent few studies have shown that the use of combination both glass and carbon fibres with either polyester or epoxy resins for making wind turbine blades. This is mainly due to higher prices of carbon based fibres or woven fabrics were the entire blade to be made up of carbon fibre is not very realistic. The current trend is focussed on making use of both glass and carbon fibre based hybrid composites for blades but until then the glass fibres will dominate in making wind turbine blades and other structures [23-25]. On the other hand increasing blade size it is necessary to arrange the fibres/fabrics made of carbon/glass in such a way that one can reach the optimal utilization of strength of these materials. In addition to this the fibre direction or orientation and thickness distribution of the overall composite are the other main design aspects to look for in the blade design.

Overall design and manufacturing of wind turbine blades is very complicated process which much must followed in order for better performance and to achieve design life. So non-destructive testing after manufacturing process and structural health monitoring during operational periods will ensure desired design life of blades [26-28]. However after manufacturing of the composite blades it is necessary to carry out inspection process to check for any manufacturing defects and need to rectify it. The repair process of such defects is very important since a small discontinuity or defect can cause failure of blades during working conditions due to rotating mass unbalance. The non-destructive testing provides important data related to surface and internal structure of blades. For instance Amenabar et al [29] using various non-destructive testing techniques like ultrasonic and X-ray for inspection of delamination in wind turbine blades. In particular ultrasonics with high penetration capability was able to detect all the delamination in the blade. In another work Jeong and Lee

[30] used laser-induced ultrasound for real time inspection of composite wind turbine blades. This mobile ultrasonic propagation imaging system demonstrated good performances as it can do inspection at high speed, non-contact and curved structural regions. In this regard present work is focussed upon the repair process of leading cracks, overbite and underbite in the glass fabric/polyester composites.

2. MATERIAL AND METHODS

Wind turbine composites blades were manufactured using polyester resin and H-glass fabric. Before manufacturing of blade, appropriate airfoil design and shaped mould was chosen as per NACA profile specifications and then were manufactured using Hand lay-up technique. During manufacturing the wrinkles of the glass fabric are smoothened by hand and flat positioning is ensured relative to that of underlying layers. Using scissors the leading and trailing edge are trimmed along with the mould edge to avoid coinciding joints in the mould. Once the fabrication is completed the blades are subjected to various inspection processes like infrared thermography, ultrasonic examination and using standard templates. Ultrasonic examination was carried out according to the ASTM standards, ASTM E317 and ASTM E1316. The examination is carried out in a non-freezing environment, with blade surface free from dust or foreign contaminants to avoid possibility of interfere with the coupling. Olympus OmniScan was used to perform inspection to measure ultrasonic response from discontinuity using a circular transducer with an active element of 25.4 mm diameter and a frequency of 0.5 MHz was used. These probes utilize ultrasonic surface waves which are highly sensitive to cracks formed during fabrication process or during operation. The propagation of ultrasonic waves take the form of a displacement or disturbance starting at a vibrating transducer and progressing through the blade, where the transmission of ultrasound energy depends on successive particle vibration. The direction of particle vibration in relation to direction of ultrasonic beam propagation determines the inspection mode. A couplant material such as water with detergent is used between the transducer and the test surface to permit transmission of acoustic energy into the part being tested. The couplant used is made sure that it is free of air bubbles or foreign materials, which may cause interference during inspections. The acoustic attenuation in wedge material and couplant mediums will vary with temperature changes. To avoid large attenuation and velocity differences in wedge materials the surface temperatures during calibration and inspection is maintained within ± 3°C. The entire repair process was conducted in a room where the temperature is closed to 18°C. The relative humidity in air was maintained well within 80%. In order to check the offsetting repairs especially related to leading edge, the standard templates were used in order to achieve a satisfactory blade profile.

3. RESULTS AND DISCUSSION

The objectives of the current work was to repair leading edge cracks in the longitudinal direction, measurement of offset, its evaluation and repair the issues related to overbite and underbite.

3.1 Case 1: Repair of leading edge cracks

In the first case we will see the leading edge cracks repair process in the longitudinal direction, outside the area with existing external root over lamination. The leading crack can be due to poor bonding surface preparation, due to presence of foreign bodies in the area of bonding or if the internal flange does not have right shape. A simple schematic of leading edge of a turbine blade is shown in Figure 1. Ultrasonic inspection performed along entire length especially the distance from leading edge to trailing edge. In this case measurement was done along the chord length directly on the up-wind blade surface. The principle of ultrasonic testing is when ultrasonic waves are transmitted into the composite material the defects like cracks influence the wave propagation resulting in local change. The crack found in the leading edge area is shown in the Figure 2a. This crack is detected using ultrasonic B-scan method and the image recorded is shown in Figure 2b.

The repair process of leading cracks in the longitudinal direction started with the chamfering the leading edge biaxial layers off. The chamfering ratio in the longitudinal direction adopted was 1:50. The chamfering of the blade area was done in order to accommodate the repair build up with 4 layers of glass fabric. Next the gel coat is removed in order to allow the smooth build up. The crack is then opened using a wedge in the leading edge and is filled with the adhesive in order to glue the crack together. But before that all chamfered surfaces are cleaned using vacuum before laminate application. The cavities appear on the surface after grinding process which is filled with glass rovings as shown in the Figure 3. Glass rovings is thoroughly rolled along the length of the blade, as air should not appear in the laminate. Close lying areas are joined together to one long repair. If the laminate thickness is inadequate to obtain the right profile, extra glass fabric is applied as shown in Figure 4. Leading edge templates are used to check the profile before, during and after the repair. Prior to finishing, re-inspection of repaired blade area is performed using ultrasonic test and finally finish operations are performed on the repaired blade area as shown in Figure 5. Most of the inspection and repair process is done manually as the thickness of the blades varies significantly. On the other hand, Hayashi et al [31] proposed the usage of robot for performing inspection of leading edge part of the blade. The experiments should successful implementation of robot of sufficiently small size using existing facilities to perform inspection and repair.

3.2 Case 2: Measurement, evaluation and repair of offsetting

In the second case we will see how the offsetting is measured, evaluated and repaired especially in connection with: overbite and underbite. Offsetting occurs when for instance the aerodynamic suction side is displaced from the aerodynamic pressure side during closure of the two blade halves. Here Overbite is the aerodynamic suction side of the blade has been displaced outwards in the leading edge relative to the aerodynamic pressure side of the blade. While underbite is the aerodynamic suction side of the blade has been displaced inwards in the leading edge relative to the aerodynamic pressure side of the blade as shown in Figure 6. In the first step we make use of standard leading edge templates to check the level of offsetting which is shown in Figure 7a. The different offsetting defects detected on the same blade are noted down which includes location, size and type of the offsetting on the blade as shown in Figure 7b. Relevant enclosures and photos that thoroughly describe the defect and repair method are noted down. If the offset is reduced in an area by cutting the adhesive joint, then the cutting area and the new level of the remaining offset is noted down.

Once the offsetting on the leading edge i.e. overbite is noted, the next step is to repair process. If the size of the offsetting is within $0 \leq x \leq 1$ mm , then the glass fabric filler is applied. Similarly if the offsetting on the leading edge i.e. underbite with the size of the offsetting is within $0 \leq x \leq 1$ mm, then the glass fabric filler is used. The severity of offsetting detected is analysed and based upon that it is determined to whether the repairing of offsetting can be done in cutting the leading edge adhesive joint. The cutting of offsetting is applicable for the small-sized defects but in order to perform the repair process the cutting of leading edge adhesive joint is generally carried out. The cutting is done in order to ease and improve the offsetting repairs as shown in Figure 8. If the entire aerodynamic suction side of the blade has been displaced forward then the cutting will not be beneficial if the adhesive flange is laminated on the pressure side. On the other hand the cutting will be helpful if the adhesive flange is laminated on the suction side blade shell, then the adhesive might have been squeezed out and the leading edge of the suction side blade shell might have been draw from the mould surface. Similarly if the entire aerodynamic suction side of the blade has been displaced backward then the cutting will not be beneficial if the adhesive flange is laminated on the suction side blade shell. This is because the distance between the bond surfaces will be increased which leads to poor bonding. As mentioned earlier here in this case also the cutting will be helpful if the adhesive flange is laminated on the pressure side blade shell.

So in cutting process, the leading edge area to be cut up is marked such that extension of approximately 1 m to each side. This is done in order to prevent the surrounding laminate from being twisted. The adhesive joint and flange in the marked leading edge area is subjecting to cutting such that the blade shell offsetting is reduced considerably. The next step is laminate matting in the area without adhesive flange and build-up of a new internal adhesive flange. Here the same H-glass type fabric and laminate build-up as that of respective blade moulding is used. Glass fabric is thoroughly rolled between each layer and the laminate is allowed to cure until the polyester has peaked and temperature is decreased to max 10°C above the room temperature. After doing this a new leading edge measurement is performed using leading edge templates to check the leading edge profile of the blade. If air bubbles or defects of small size appear around in the repaired area, then cleaning is performed and re-filling of glass fabric filler is carried out.

In many offsetting instances, adhesive may be lacking between blade shell and adhesive flange in the leading or the trailing edge. This is due to the fact that overbite or underbite situations might increase the distance, as when a blade shell is moved away from the adhesive flange. In such cases a plastic hammer may be used for tapping on the blade surface, and areas lacking adhesive will sound hollow. Along with this visual inspection of the adhesive flange as far inside the blade as possible is conducted to check for cracks or any other defects may appear on the adhesive flange. It is followed by grinding off the gelcoat the blade surface in an area corresponding to the adhesive area on the adhesive flange. Check for areas lacking adhesive, i.e. light stains in the surface or using ultrasonic testing. Further in case of both overbite and underbite situations if the offset is 1 - 3 mm then using leading edge templates the extent of the countersunk area to be repaired is determined. This starts with the grinding of gelcoat in the countersunk area to be laminated as shown in Figure 9. The width and length of the layers to be applied are determined using the leading edge templates. Take into account that the large-sized layer (largest width and length) is applied first. If the extent of the repair in the longitudinal blade direction necessitates the application of additional glass lengths then apply the same glass fabric layers edge to edge in the longitudinal blade direction as shown in Figure 9 and 10. Again glass fabric is thoroughly rolled between each layer in avoid to avoid air entrapment and the laminate is allowed to cure until the polyester has peaked and temperature is decreased to max 10°C. Prior to finish re-inspection of repaired blade area is performed and the finishing operations on the repaired blade area are done. Re-inspection of repaired blade area is carried out again by ultrasonic inspection (B-scan method) method to ensure no defect is present. These mentioned procedures will ensure no defects are present after repair process and blade can be used for operation. In this regard, Marsh [32] briefed above spot repair of impact pit in leading edge using translucent resin to avoid future possibility of moisture absorption into the laminate.

CONCLUSIONS

In present work we have shown the detailed repair process related to crack and offsetting in wind turbine blade made up of glass fabric reinforced polyester composite material. The conclusions drawn from the work are,

(i) Successful identification of crack in particular leading edge cracks in the longitudinal direction, outside the area with existing external root over lamination using ultrasonic B-scan method.

(ii) Repairing the crack by chamfering the surfaces, cleaning with vacuum, filling it with glass rovings and rolling the rovings in order to avoid air entrapment.

(iii) In second case offsetting is measured, evaluated and repaired especially in connection with: overbite and underbite. Offsetting is within $0 \leq x \leq 1$ mm is repaired by using glass filler materials.

(iv) For offsetting of 1 - 3 mm, glass filler materials are used, rolled and cured. Using leading edge templates the repaired blade is area is re-inspected.

Overall the work highlight the addressing of post manufacturing defects like cracks and offset in the wind turbine blade especially when the aerodynamic suction side is displaced from the aerodynamic pressure side during closure of the two blade halves. The repair process are necessary to they can damage blade during working conditions which can lead to serious secondary damage to the whole turbine due to rotating mass unbalance

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BIOGRAPHIES

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FIGURE CAPTIONS

Figure 1 Schematic of blade depicting leading and trailing edge.

Figure 2 (a) Leading edge crack detection in the longitudinal direction and (b) crack detection using ultrasonic B-scan method.

Figure 3 Application of roving in the repaired area

Figure 4 Schematic of leading edge crack repair process

Figure 5 Final inspection of repaired leading edge to check for irregularities

Figure 6 Overbite and underbite in blade

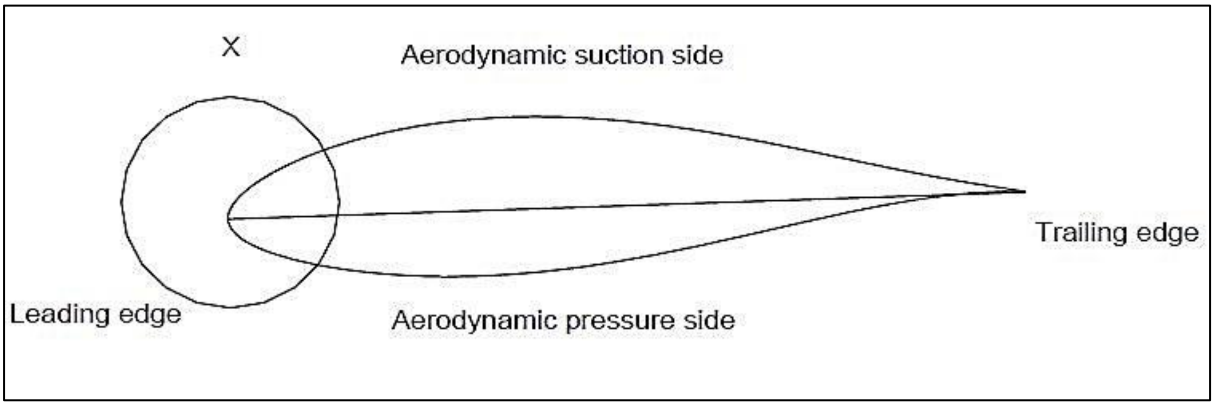
Figure 7 (a) Leading edge template to check the level of offset and (b) recording the size of offset.

Figure 8 Illustration of cutting of leading edge adhesive joint

Figure 9 Grinding and application of glass filler in of case overbite repair.

Figure 10 Application of glass filler in case of overbite repair that is leading edge offset

FIGURES



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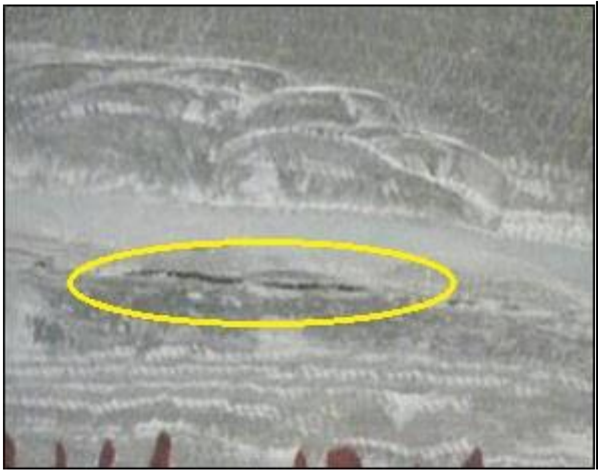

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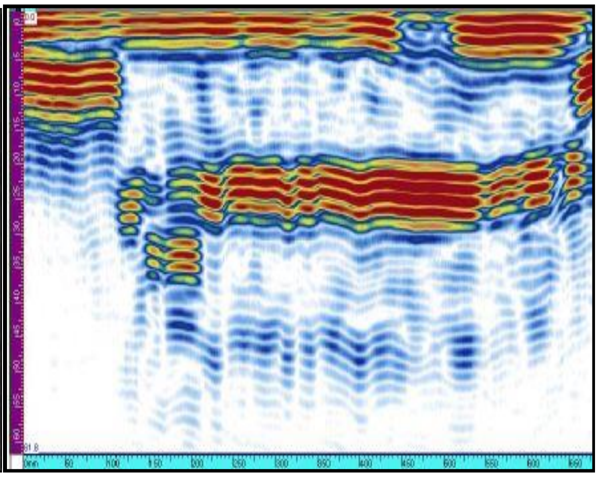


(b)

Figure 2 (a) Leading edge crack detection in the longitudinal direction and (b) crack detection using ultrasonic B-scan method.

Figure 3 Application of roving in the repaired area

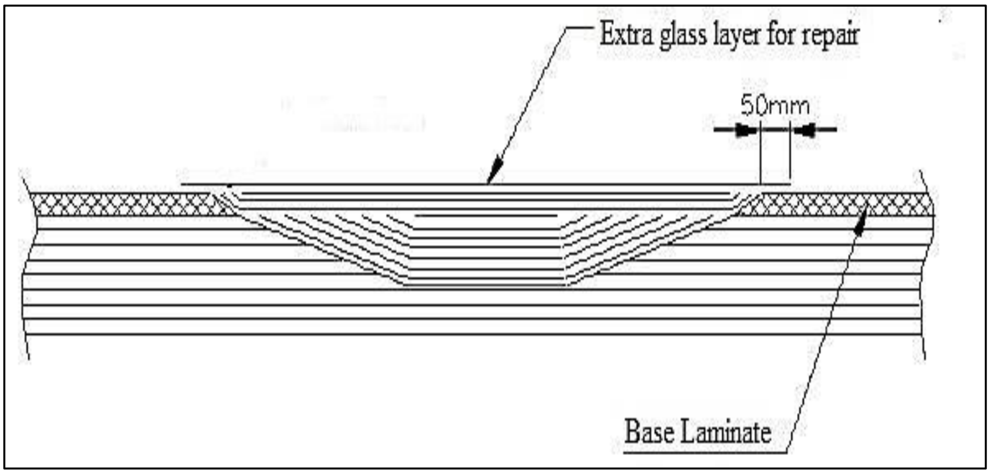
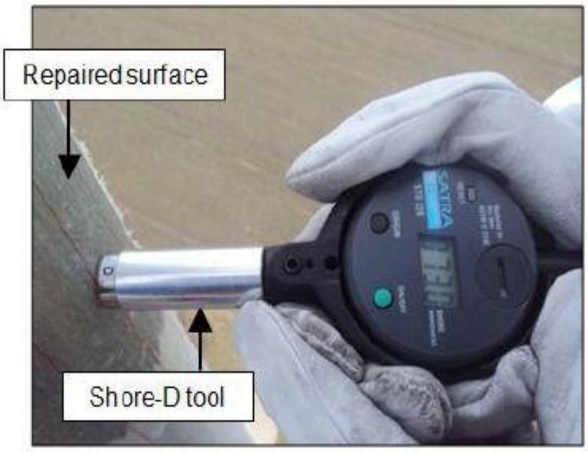


Figure 4 Schematic of leading edge crack repair process



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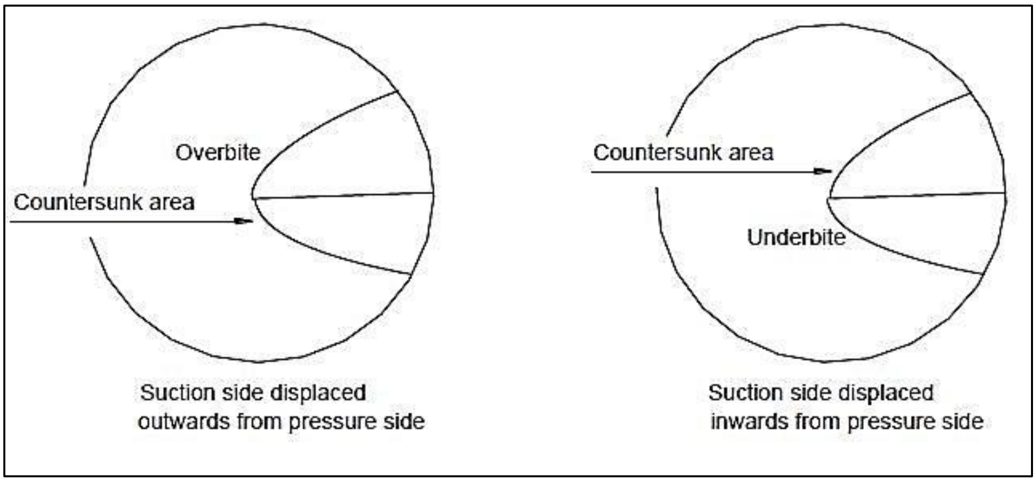

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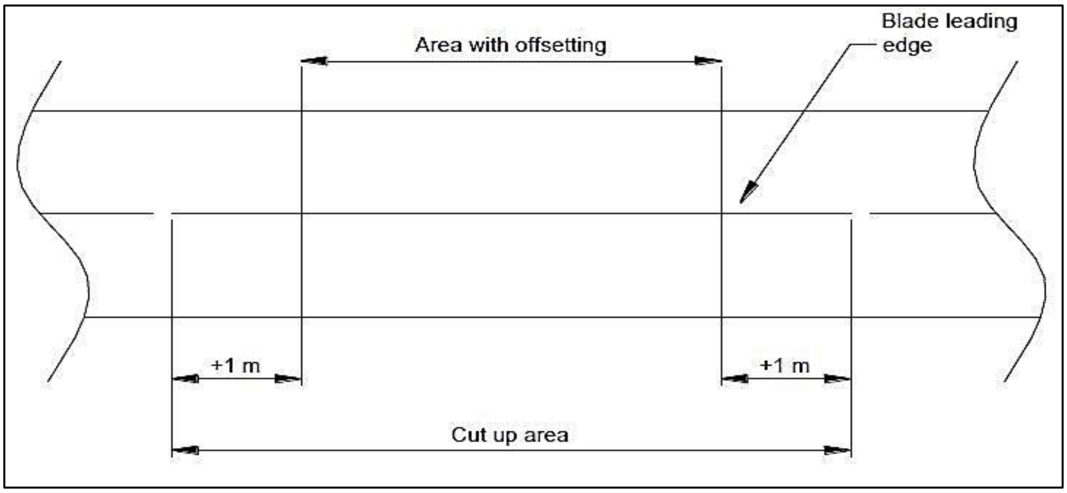

Figure 8 Illustration of cutting of leading edge adhesive joint

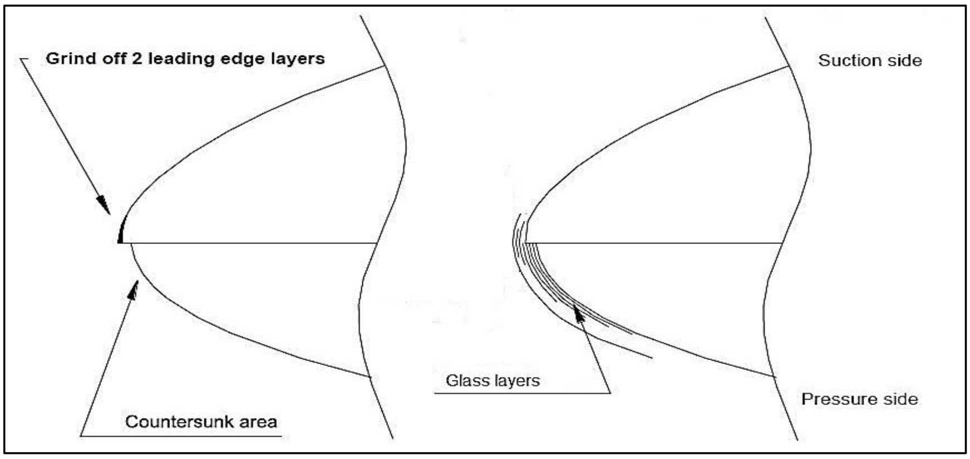

Figure 9 Grinding and application of glass filler in of case overbite repair.

Figure 10 Application of glass filler in case of overbite repair that is leading edge offset