FAILURE INVESTIGATION OF BELL 412 MAIN ROTOR BLADE TRIM TABS AND STUDY OF SUITABLE ADHESIVE MATERIAL APPLICATION WITH A NEW TRIM TAB DESIGN

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Degree of Master of Science

Department of Materials Science and Engineering

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This Dissertation submitted in partial fulfillment of the requirements for the Degree of Master of Science in Material Science.

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Declaration

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Signature of the Supervisor : Date :

Abstract

The Bell 412 helicopter is a type of aircraft in the Sri Lanka Air Force (SLAF) inventory which is accorded specialty status due to its role in the transportation of VVIPs in Sri Lanka. Over three decades of operation, the failure of trim tabs, a bigger issue of Main Rotor Blades (MRBs) have been identified. MRB is a glass fibre construction and the titanium trim tabs are bonded by manufacturer-recommended adhesives. This failure could hamper the efficient usage of the helicopter operation and may result in the blade being inoperable. This issue currently persists and this research is focused on a study of the failure of the Bell 412 main rotor trim tab and explores the possibility of a suitable adhesive material application with a new trim tab design to resolve the problem. During the initial findings, it has been observed that the prevalent condition is attributed to the failure of the adhesion between the trim tab and the Main Rotor Blade. To identify the root causes, adhesion properties were tested using a modified floating roller peel test (FRPT). Further, the fracture mechanism was observed and Differential Thermal Analysis (DTA) techniques were utilized.

In this study, it was also observed that the original design of the trim tab itself propagates the failure and thus, another area of focus in this research was to optimize the design of the same. In addition, the study proceeds to investigate suitable adhesive material properties which would be better suited to resolve this critical issue.

Keywords*:* Main Rotor Blade, Helicopter, Trim Tabs, Glass Fibre, Honeycomb, Titanium Alloys, Adhesives, Composite.

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Finally, I wish to express my sincere gratitude to my parents, wife, and all my family members for helping me in numerous ways to achieve success in my higher studies.

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Abbreviations

OEM - Original Equipment Manufacturer
SLAF - Sri Lanka Air Force
MRB - Main Rotor Blade
DS - Daily Servicing
FRPT -Floating Roller Peel Test
DSC - Differential Scanning Calorimetric
RAT - Rapid Test method
CPT - Composite Peel Test
DTA - Differential Thermal Analysis
Tg - Glass Transition Temperature
RT - Room Temperature
SEM - Scanning Electron Microscope
ASTM - American Society for Testing and Materials

1. Introduction

1.1 Failure of Trim Tabs

The discussion of composite materials and application of the same is vital to many fields. Aviation one such major area and it has become an essential requirement due to innumerable resultant advantages. However metallic structures are still in operation and when it comes to the joining of both metallic structures and composites together, adhesive bonding is the most efficient and widely used joining technique in terms of weight and performance. Thus, composite-to-metal bonded joints are commonly used in the field of aviation.

This study is primarily dedicated to the study of the failure of trim tabs (composite-metal bonded joint) in a short span of time and seeks to find the root causes for failure, while exploring possible solutions to repair the same. The Bell 412 main rotor blade is a composite construction of glass fibre and titanium alloy trim tabs, which are bonded by adhesives recommended by the manufacturer. Figure 1 shows the typical arrangement of a Bell 412 helicopter MRB which is constructed by a glass fibre spar and a paper honeycomb core and is bonded internally to make the desired aerofoil shape. Finally, the entire blade is covered with a glass fibre skin and three trim tabs are adhesively bonded to the glass skin of the blade (Figures 2 and 3). In this arrangement, over a span of operation comprising nearly three decades, the failure of the trim tab was observed in the various life stages of the blade and is a cause for crucial failure in the main rotor blade. Unlike other components, the blade has no guaranteed lifespan to be considered obsolete. However, the Bell 412 main rotor blade trim tabs failure results in various issues for the blade and subsequently leaves the blade inoperable. This is a very sensitive area and a major unsolved problem existent with Bell 412 helicopter blades. The failure of the trim tab during the rotation of blades can cause severe adverse effects for the aircraft in structural damages and compromises the comfort of passengers due to excessive vibration. Considering that such aircraft is primarily used for the transportation of VVIP/VIP passengers by the Sri Lanka Air Force, due attention has already been taken to avoid such conditions. Despite the past maintenance history of the Bell 412 main rotor blade and frequently drawing attention towards this failure, little research has been directed towards the rectification of this issue. Informing the OEM resulted in the replacement of trim tab as a solution, after the observation of such failures. It is speculated that similar issues may have been observed by the other operators worldwide though no technical directive has been given by the OEM concerning the matter of extending the life of trim tab on the blade.

Therefore, the aim of this research is focused on studying the failure of the trim tabs of the Bell 412 main rotor blade and find its root causes, with a new technical approach. This study produces a systematic approach to evaluate the bonding strength of the trim tabs and provides feasible solutions to improve the lifespan of a trim tab. This is a novel area of study which has not been previously undertaken by Bell 412 helicopter maintenance operators and it is primarily advantageous to improving the durability of the blade and in improving the flight safety aspects of the same. Further accrued benefits include the cost savings associated with these findings – a considerable sum of money is spent for the replacement of tabs and extending the lifespan of the blades. Notably, this study has the potential to open new areas for researchers to develop new adhesives for this application, further improving the blade construction.

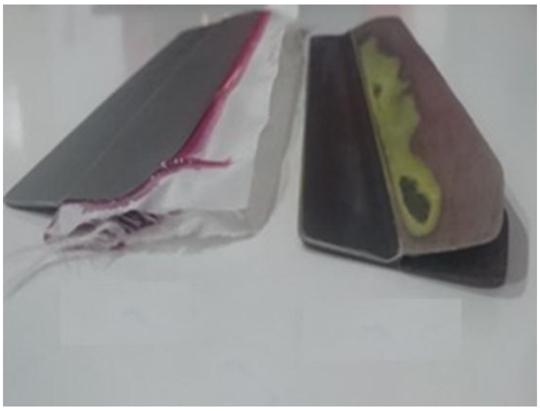

Figure 1 : Bell 412 Main Rotor Blade

Figure 2 : Trim tabs of the Bell 412 Helicopter

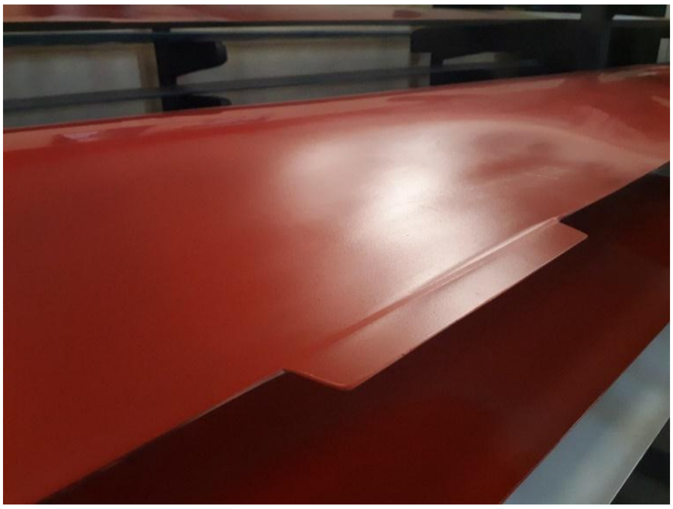

Figure 3: Tab installation on Bell 412 blade

1.2 Background Study

The trim tab is a vital subcomponent of any Main Rotor Blade (MRB) of Helicopters and is used for rotor tracking and balancing and smoothening the vibration in the airframe, caused by the MRB. The Bell 412 helicopter is considered important in the helicopter inventory of the Sri Lanka Air Force (SLAF) and is used mainly for VVIP/VIP flights. In this respect, it acquires an exclusivity, requiring its own maintenance philosophy more suited for its role and which differs from other aircraft in the fleet of the SLAF.

The de-bonding between the trim tab and the MRB was experienced from the inception of the use of Bell 412 helicopters in the SLAF. According to the past history, this matter was brought to the notice of OEM and the only possible repair was the authorization to replace the trim tabs. It was observed that these de-bonds and the replacement of the tabs incurred a considerable revenue outflow from the country. Presently, the failure of the trim tab joints was observed as initially starting from the periphery and subsequently developing towards the inside of the trim tab. There are three trim tabs available in the Bell 412 helicopter and they are called Inner-board trim tab, Mid-board trim tab and Out-board trim tab respectively. Tabs are subjected to two types of loads called aerodynamic loads and bending loads. Preliminary studies found that this issue is initiated due to the failure of the trim tab and the bending loading which is applied on ground during the trim tab adjustments. In this tab adjustment, the tab is bent by a tool (tab bending tool) and adjusted to the desired angle. Furthermore, the tab is subjected to aerodynamic loads which is applied during the rotation of blades and it is the dynamic loading condition of the tabs.

As per observations made over the years, the major issue identified is the failure of the adhesive bond and which renders the existing tabs unusable. It is important to distinguish that this replacement is done only due to the failure of the adhesive and not due to the failure of the tabs. When considering the adhesives used in maintenance history, three types of adhesives play the role of bonding adhesives. Film adhesive (AF 163 2K) was the initial adhesive used for the bonding of tabs and the other two adhesives (Magnobond 6367 and Magnobond 6398) are being used at present. Film adhesive (also known as paper adhesive) was the first type of adhesive used and OEM still uses the same for the bonding of tabs. During maintenance, OEM has given instructions to use the film adhesive only for blade repairs at Bell Helicopters approved blade repair facilities. The Rotor Bay is the place where all the repairs of blades are carried out by the Sri Lanka Air Force and some OEM approved repairs are done at this facility. However, for balance repairs, these blades have to be sent to Bell Helicopter approved repair facilities overseas. Moreover, the rotor bay facility at SLAF is not considered as an approved repair facility as it is a military establishment. Therefore, film adhesive usage was terminated and two adhesives were introduced for tab repairs. The SLAF shifted to the use of the two new adhesives and after a period, the maintenance crew observed that the failure rate of trim tabs had extensively increased to a considerable level. Accordingly, this was informed to the OEM for a remedial solution but no avail. The only instruction offered by the OEM was to replace the tab once such failures were observed.

As illustrated above, this topic is timely and relevant to the operational and maintenance perspective of the SLAF in the following aspects.

a) The Bell 412 helicopter is a prime aircraft for VVIP/VIP operations and failure of the trim tab causes adverse effects on aircraft and passenger comfort. Further excessive vibration can cause a total failure of aircraft.

b) Tabs bonded with film adhesive operate for more than an average of 1000 flying hours whereas tabs bonded with new adhesives operate for 150-200 hours.

c) The Bell 412 MRB is a construction of glass fibre composite construction. The core consists of paper honeycomb and the glass fibre outer layers are bonded in order to sustain the aerodynamic contour. Due to the damage which occurs at the trim tab, the MRB is exposed to the external environment and this leads to water penetration – this condition was experienced on several occasions. This leads to the blade being inoperable and obsolete. The cost of the blade is approximately US$ 400,000 (approximately Rs. 72,000,000.00) which is exorbitantly priced. [1]

d) Trim tab damages occur at various stages of the life of the blade and the replacement of a trim tab costs approximately US$2000 (approximately Rs. 360,000.00)[2]. A proper approach could result in large cost savings. Considering the number of blades in operation in the SLAF (nearly 50, 412 blades are recorded in its inventory) and with each blade having three tabs on its construction, this is a waste of colossal proportions.

1.3 Aim

Aim of this research is focused on studying the failure of the trim tabs of the Bell 412 main rotor blade and find its root causes, with a new technical approach. This study produces a systematic approach to evaluate the bonding strength of the trim tabs and provides feasible solutions to improve the lifespan of a trim tab.

1.4 Research Objectives

As highlighted above, trim tab failure is a critical area with respect to the maintenance of the Bell 412 main rotor blades in the SLAF and the objective of this research is to investigate the failure of the bell 412 main rotor blade trim tabs and the study of suitable adhesive material application with a new trim tab design. To achieve the above, the following will be undertaken.

- To identify the root causes for the failure of trim tabs.
- Examine the failure of trim tab related maintenance practices of the Bell 412 MRB.
- Investigate the adhesion properties of previously used adhesive and new adhesives and attempt a comparison of both
- Optimizing the design of trim tab for Bell 412 helicopter MRB for increased efficiency
- Investigate adhesive material properties suited for bonding
- Propose further recommendations to investigate the design failure of the present trim tab and solutions to overcome trim tab failure

2. Literature Review

2.1 Reasons for failure of the trim tabs

Due to the failure of the trim tabs of Bell 412 aircraft, there are a number of incidents reported in the past. According to reported incidents, the following information was gathered from available resources.

a) **Cracks on the trim tab boundary edges**

This is the most prominent type of failure of the MRB. During the Daily Servicing (DS) and After Flight (AF) inspection on such observation, the MRB is sent for rotor blade repairs at Rotor Bay, Aircraft Engineering Wing, SLAF Katunayake. This is characterized by adhesive edge crack and propagates further damage. As per the OEM's directives for this condition, the tab is to be replaced.

b) **De-bond on the trim tab**

After observation of such conditions, it is noted that this is characterized by adhesive edge crack and results in further damages. As per the OEM's directives in accordance to this condition, the tab is to be replaced. During the taping test, some MRBs generate a unique dull sound stemming from the trim tab areas and on such occasions, blades are inspected thoroughly to identify the failure. These failures could be indicative of de-bonds failure occurring on the glass fibre blade surface or de-bonding between the blade and the trim tab. Figure 4 shows the surface of blade after the removal of the trim tab due to the de-bond on the same.

c) **Water penetration**

This is the most severe damage which can be found on the MRBs. Because of this condition, the paper honeycomb is affected and ultimately the structural integrity of the MRB will be distorted. The root cause for this is mainly due to an unidentified de-bonding area of the trim tabs. In such situations, the blades are rendered completely unusable.

Due these above issues observed, a number of MRBs have been discarded while many flight-related incidents have been reported by the aircrew and the maintenance crew. At present, the only maintenance action which is undertaken is the replacement of tabs after the observation of such incidents. To circumvent these issues, action has been taken and present remedial measure are taken in to account as a reference guideline.

Figure 4: Removed tab of a de-bonded tab

2.2 Determination of bonding strength of the adhesive bonds

This failure is dealt with the joining of glass fibre composites to metal and a critical aspect is the long-term durability of adhesion at the interfaces. The most important parameter for assessing the interface adhesion is assuring the integrity of composite–metal bonded joints. A peel test is a suitable destructive test. Peel testing is used to determine the adhesive bonding strength and it is used as a qualitative measure, as well as an evaluation aid for adhesive selection for various purposes. Two commonly used peel tests are the climbing drum peel test, ASTM D1781 [3] and the floating roller peel test, ASTM D3167 [4]. The climbing drum peel test is used mainly for the evaluation of a bonded sandwich structure and it can be used for metal-to-metal bonds. The floating roller peel test is exclusively used for metal-to-metal bonds [5]. When considering the modern testing techniques, interface adhesion is assessed by using destructive testing techniques. For metal bonds, a widely accepted industrial test is the standard floating roller peel test. This is a fast and reliable test to assess metal bonding adhesion [6]. Significant research has been performed using these types of peel tests for metal bonding with diverse objectives, the effect of surface pre-treatments, adhesives screening, bond durability, etc. Diverse studies have also investigated the adherent effects in the floating roller peel test. It has been found that the peel strength measured is a combination of the true interface adhesion strength and work expended in the plastic deformation of the thin adherent [7].

The standard floating roller peel specimens were based on the ASTM D-3167 standards. As per the ASTM D-3167 standards a 1.6 mm thick aluminium sheet (rigid adherent) was adhesively bonded to a 0.5 mm thick aluminium sheet (flexible adherent). During testing, the flexible adherent is peeled off from the rigid adherent. Both aluminium adherents were clad Aluminium alloy 2024. Prior to bonding, the aluminium surfaces were pre-treated with chromic acid anodizing and primed with BR 127 (Cytec Engineered Materials, Tempe, Arizona, USA).[8]

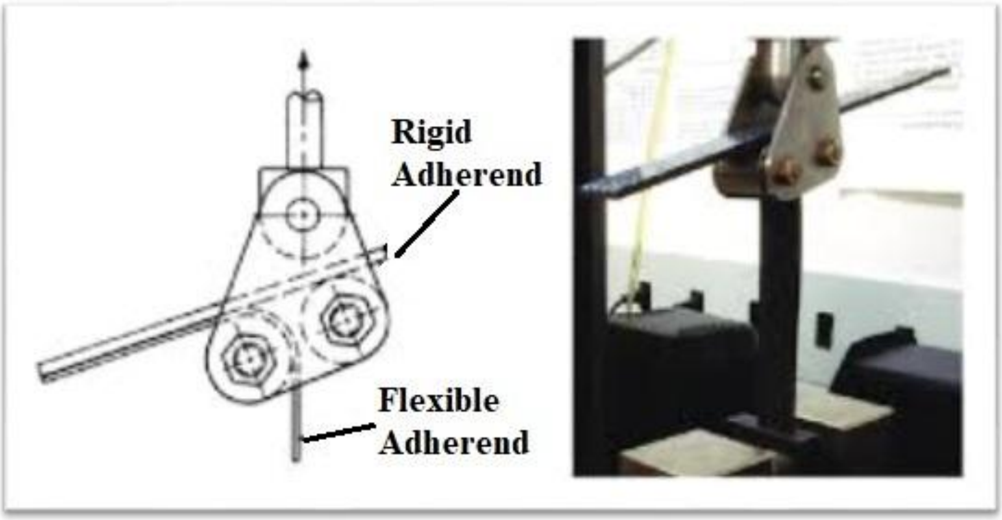

Figure 5 : Floating Roller Peel Test [9]

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Figure 5 illustrates the general arrangement of the floating roller peel test and in Method D-3167, the peel strength is determined by dividing the average peeling load by the specimen width. This procedure does not distinguish quantitatively between the percentage of the load required to fail the adhesive and the percentage of the load required to deform the flexible adherent. Rather, the total load necessary to both deform the flexible adherent and fail the adhesive is used to calculate the peel strength of the subjected adhesive. However, variations in properties of the flexible adherent (yield stress, stiffness, thickness, etc) will influence the test results. For this reason, this test method can at best be used for direct comparison of different adhesives only when specimen construction and conditions are kept as identical [10]. A few studies were found on the development of rapid peel tests for composite bonding. Van Voast and Flinn have suggested a Rapid Test method (RAT) for adhesion in order to evaluate surface preparation of composite parts [11]. Another modification to the floating roller peel test has suggested by Holtmann Spotter, in which the Aluminium rigid adherent is replaced by a composite rigid adherent. The thin adherent remains of Aluminium as in the standard test. However, due to the asymmetry of the floating roller peel test, the interface being tested is the one on the thin adherent. Therefore, if using Aluminium for the thin adherent, the tested interface is the Aluminium/adhesive and not composite/adhesive, the interface of interest. [12]

Further use of peel tests is reported in Riul et al. In this study, peel tests are used to compare the inter-laminar strength of composite laminates with different manufacturing process. This shows the wider potential of peel tests, not only limited to secondary bonding applications but also to co-cure composite laminates. [13]

Presently a new test called Composite Peel Test (CPT) was introduced for assessing interface adhesion of composite bonded structures. This study is a follow-up of the previous study performed by the authors in which different combinations of adherent composite vs. Aluminium was investigated [14].

2.3 Differential Thermal Analysis (DTA)

Thermal analysis has played an important role in the development of adhesives to long term usage of adhesives, considering different intended purposes. Thermal analysis techniques are used to determine if epoxy adhesives have advanced beyond the useful state of cure and in determining the glass transition and degree of cure. Further, these techniques are used to find the amount of moisture and volatiles present in a material, as well as measuring the mechanical properties of the same such as contraction, expansion, and modulus [15]. It is similar to Differential Scanning

Calorimetry (DSC) being used to analyse a material's Glass Transition (Tg)[16], degree of cure and cure state condition. It provides details to characterize melting and softening behaviour, and quantify crosslinking reactions [17]. By measuring heat absorbed or heat involved by the sample as it is heated (or cooled) under a controlled temperature and atmosphere, DSC is able to record changes in specific heat capacity and latent heat that indicate changes in the crystalline and amorphous structures. DSC gives a direct indication of the adhesive system, mainly the Glass Transition (Tg) region.[18]

The epoxy adhesives currently used consist of resin and hardener mixture for usage as per the manufacturer recommended ratio. In addition to this, film adhesives represent resin and hardener mixtures that are cased in to film and partially staged (partially cured). During the DSC testing when the temperature is increased, the cross-linking (curing) reaction proceeds and that shows a large exothermal reaction in the DSC curve. The higher amount of Tg shows the maximum cross linking adhesive and therefore that carries a higher amount of bonding strength. [19]

2.4 Fracture mechanism

During the peel test, the failure may be a cohesive or adhesive failure. When the adhesive bond is stronger than the adherent used, cohesive failure occurs. Sometimes the combination of both cohesive and adhesive failure occurs at the interface. Cohesive failure leads to fracture of the adherent. During the peel test failure occurs at the interface and pictures of the fracture surfaces of two adhesives scanned by the electron microscope are shown in Figure 6 which was observed from previous research. [20]

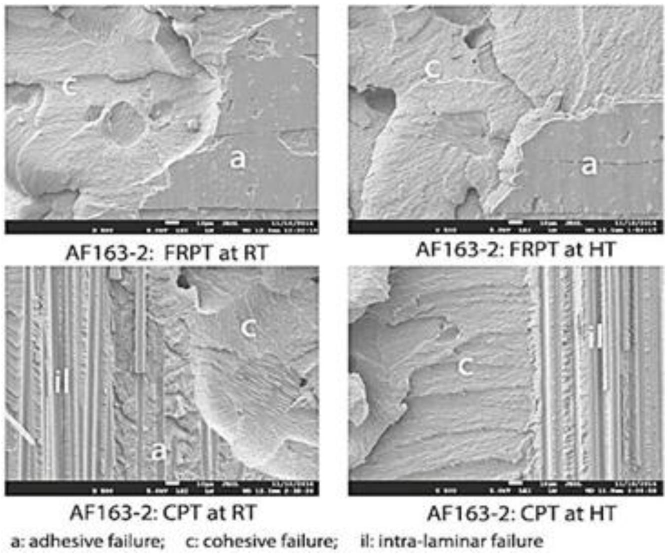

Figure 6: Fracture mechanism [21]

Two Peel tests have been carried out as FRPT (Floating Roller Peel Test) and CPT (Composite Peel test) at room temperature (RT). AF 163-2 is the adhesive used during the test. The pictures above show ‘a’ as an adhesive failure, ‘c’ as a cohesive failure and ‘il’ as an intra-laminar failure. Intra-laminar failure of the composites has indicated good adhesion, since the failure is cohesive within the composite adherent and not at the interface. Furthermore, this type of failure also indicates that the intra-laminar strength of the composite adherent is lower than the de-bonding strength of the adhesive. The above peel tests also concludes that in most cases of good adhesion, increasing the temperature favours cohesive failure of the adhesive in detriment of intra-laminar failure of the composite. The fracture mechanism of a cohesive failure is independent of the peeling-off adherent (composite or Aluminium). [22]

3. METHODOLOGY/ ANALYSIS SET UP

3.1 Determination of adhesive bonding strength

As per the research objectives, the initial stage of the failure of trim tabs was studied in the macroscopic scale with evidence presently available in resources. By analysing the gathered data, it was identified that the particular failure has a de-bond initiation and propagation is also in the similar nature. The analysed data clearly points out that the failure is a mode of adhesive failure and is promoted by the design itself. Accordingly, as per the outlined objectives, the research was first directed towards determining the bonding strength of the particular adhesive bond. Peel tests are used to determine the bonding strength of different adherends and widely used tests and research areas discovered by researchers were found during the background studies.

In the maintenance of rotor blades while bonding trim tabs to blades, there are two adhesives used for this purpose, namely Magnobond 6367 and Magnobond 6898. Standard floating roller peel test is used to determine the peel bonding strength of the adhesive which lies between a rigid adherend and flexible adherend. Furthermore, this standard floating roller peel test was modified as per the specific requirements for research purposes, to determine the bonding strength of adhesives in between the glass fibre and titanium alloy. During the failure of trim tabs, glass fibre skin is kept stationary and the titanium tab is de-bonded from the blade surface. Glass fibre skin acts as a rigid adherend and the titanium tab acts as a flexible adherend. Accordingly, samples were prepared on the same phenomenon. Samples were prepared using both adhesives.

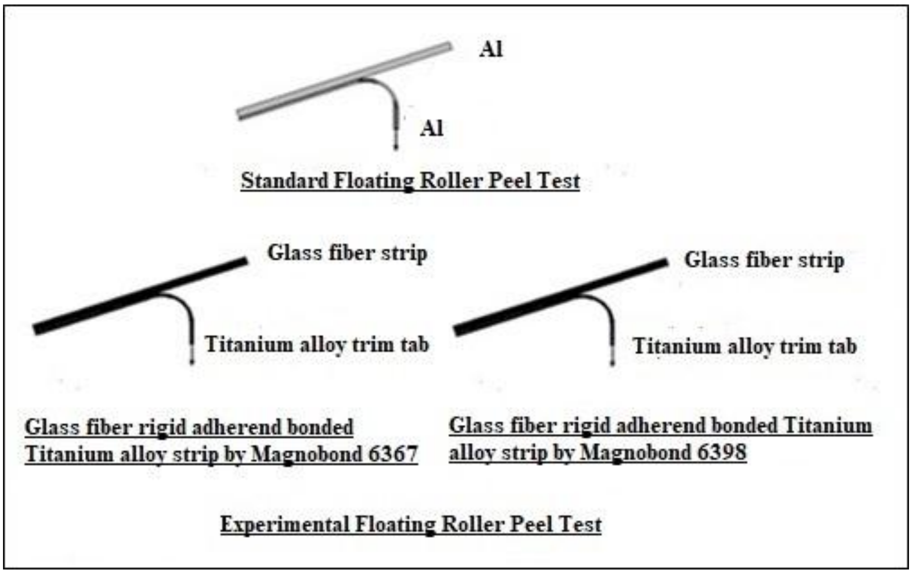

Figure 7: Standard floating roller peel test vs experimental floating roller peel test setup

(Magnobond 6367 and 6398 laid between flexible and rigid adherend) [23]

As illustrated in Figure 7, samples were prepared by using both adhesives with the glass fibre strip as the rigid adherend and the titanium tab strip as a flexible strip. In the case study it was found that the adhesive bonding lies between two substances such as the glass fibre skin and the titanium alloy surface. As per the findings over the years with regard to this failure, it was observed that the titanium alloy tab peeled off from the glass fibre during the initial part of the failure. The standard Floating Roller Peel Test (FRPT) was developed for the testing of metal to metal bonding and according to the research requirements, standard Floating Roller Peel test was modified to be used with glass fibre composite and titanium alloy bonding. Here, the glass fibre skin retains as the stationary substance and it is selected as the rigid adherend and the titanium alloy strip, as the flexible adherend.

3.2 Sample preparation

Samples were prepared using two types of adhesives namely Magnobond 6367 and Magnobond 6398. These are the recommended adhesives for the use of the said adhesive bonding between the trim tab and glass fibre skin by the manufacturer. Samples were prepared by using titanium alloy tabs which were removed from discarded trim tabs and the glass fibre rigid adherend is made of glass fibre cloths with hand lay-up technique. After the making of the glass fibre rigid adherend plate, titanium strips are bonded as per the following bonding procedure as prescribed by the manufacturer.

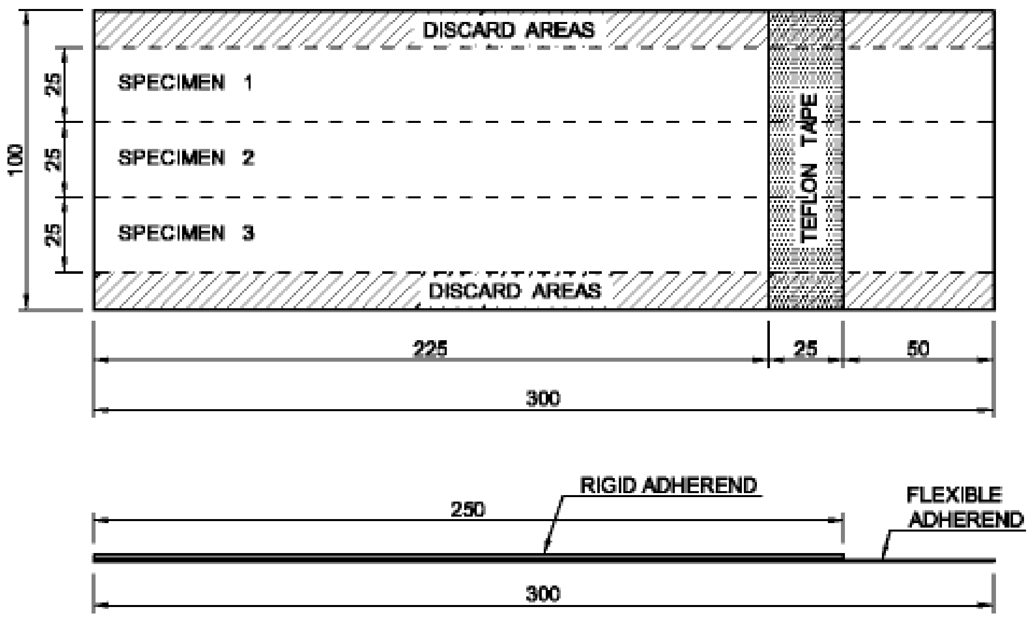

Figure 8: Sample preparation references [24]

The bonded panels were prepared as 100 mm wide by 300 mm long and after cured, the bonding test specimens were cut into 25 mm wide specimens. [20] A quantity of 05 samples were prepared from each adhesive and a total of 10 samples were prepared.

After the preparation of the fibre glass rigid adherend, titanium alloy trim tabs which were removed after its use in service were cut into the size which matched the above specifications. Finally, tab strips were bonded to the glass fibre rigid adherend with Magnobond 6368 and Magnobond 6398 as per the prescribed procedure of the OEM. Following are the special conditions which have to be maintained for the bonding process of the trim tab to the main rotor blade. Table 1 shows the adhesive types used and the bonding temperature parameters for each type.

Table 1: Bonding process temperature of adhesives

Type	Bonding at room temperature	Hot bonding
Magnobond 6397	24 hours	155 – 165 ^{0}F (69 – 74 ^{0}C) for 2 Hrs
Magnobond 6398	24 hours	155 – 165 ^{0}F (69 – 74 ^{0}C) for 2 Hrs

3.3 Floating roller peel test fixture

To perform the floating roller peel test, D 3147 floating roller fixture is essentially required. However, to this floating roller fixture was unavailable in Sri Lankan lab facilities. Therefore, during the research, the manufacturing of the D 3147 roller fixture was done as additional work in accordance to the set standards.

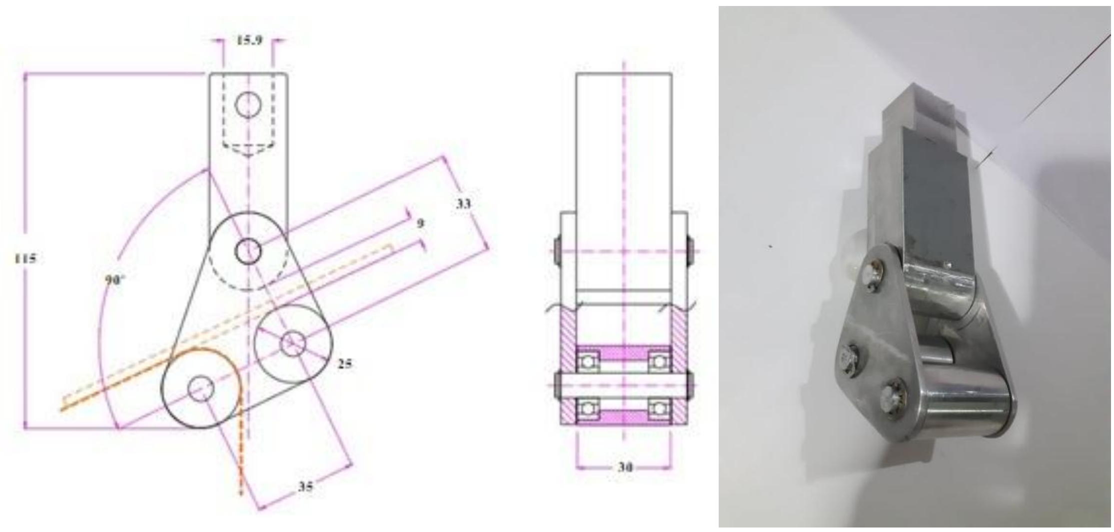

Figure 9: Prepared floating roller peel test fixture as per the D 3147 standard dimensions

4. Results and Discussion

4.1 Floating roller peel test

The floating roller peel test determines the peel strength between rigid and flexible adherend and in this research, tests were performed using the Electro Mechanic Unitester machine which has a maximum capacity of 10 kN. The testing speed of the same was 6 mm/min and during the test, the flexible adherend is peeled off from the rigid adherend [21]. Figure 10 shows the test setup and Figure 11 load-displacement curves that were recorded during the tests.

Figure 10: Experimental setup for floating roller peel test

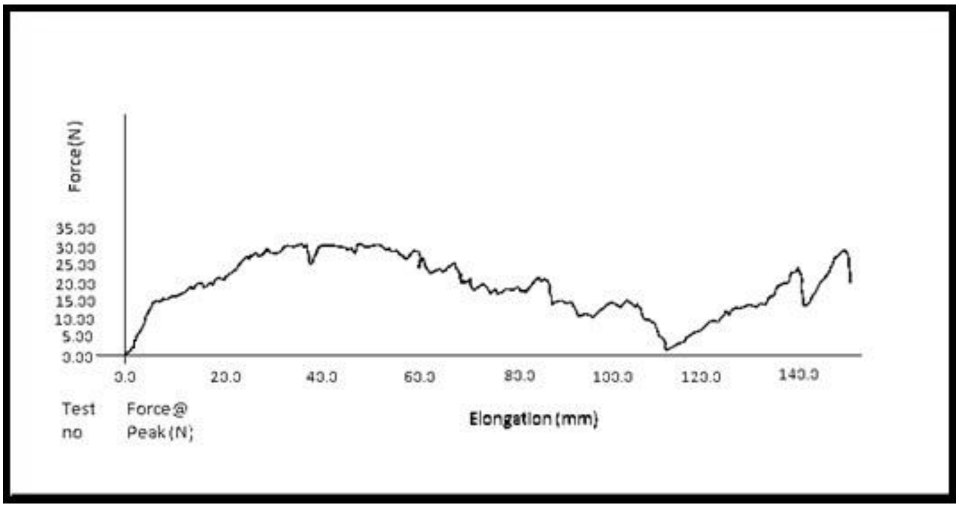

Figure 11: Distance vs. load curve generated by the floating roller peel test

Prepared samples were tested for the floating roller peel test and the distance vs. load variation was plotted as above. According to the floating roller peel test, two results can be observed from the peel test as the failure mechanism and the peel strength of the adhesive bond.

The first test was done against the bonding strength of Magnobond 6367 in between titanium tab strip and glass fibre strip. It was noted that the average peel strength of the Magnobond 6367 was about 9 newton and for the same construction average peel strength for Magnobond 6398 was about 10 newton. These results showed similar behaviour during the peel test performance of both adhesives. The actual peel strength which was experienced during the removal of the trim tabs from the blade in a practical scenario is much higher than this resulted value. Therefore, the test was repeated and the same result was observed. During the removal of the tab, it was noted that it had experienced a significant amount of strength than the results observed in the experiment. During the experiment this result was extended to a new research area while analyzing the experimental setup. The above results are tabulated in Table 2 as follows.

Table 2: Peel load and maximum peel strength of presently used adhesives

Type of Adhesive	Peel Load (N)	Maximum Peel Strength
6367	9	9N/25mm = 0.36 N/mm
6398	10	10N/25mm = 0.4 N/mm

The two adhesives Magnobond 6367 and Magnobond 6398 presently used are manufacturer recommended adhesives exclusively used for the bonding of metallic structures and fibre constructions. However, based on results, the above adhesives do not have sufficient bonding strength in between the titanium metal and fibre construction. After observation of the above results, further study of this issue was examined.

It is found that the tab which is provided by the manufacturer has an additional construction on the Trim tab. Here, the trim tab has an additional film adhesive layer bonded to the inside of the trim tab and during the tab bonding the adhesives (Mangnobond 6367 and Magnobond 6398) is bonded to glass fibre from one side while a film adhesive layer is bonded from the other side. This is an additional matter to be considered and therefore the experimental setup was changed to simulate the actual bonding of the trim tab. As mentioned in the maintenance publications, it is a bonding between the glass fibre and titanium alloy tab, and as found during the practical use of the tab, it does not bond with the titanium surface. Instead, it bonds with the adhesive glass fibre blade from one side and on the other side, it is the film adhesive layer. However, the case study was focused on determining the bonding strength between the titanium tab and glass fibre and with this new finding, the experimental setup was changed to simulate the same as follows.

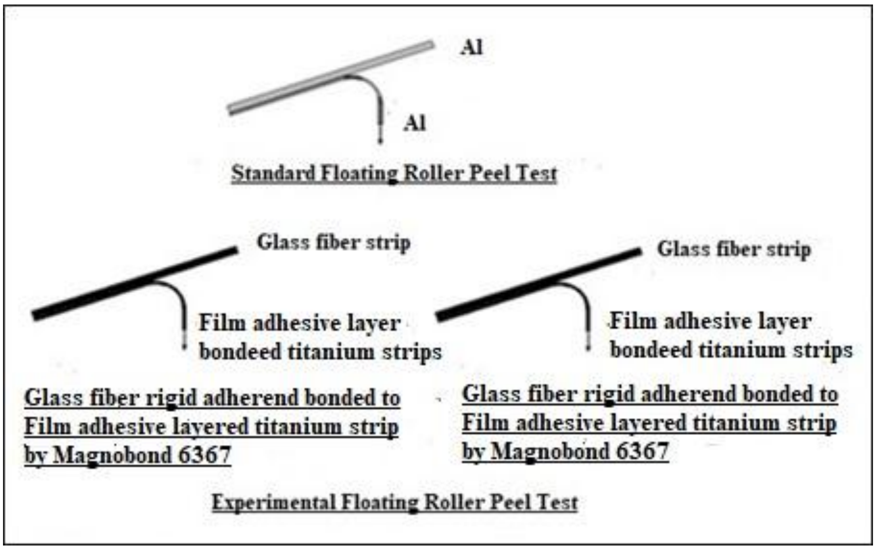

Figure 12: Standard floating roller peel test vs. experimental floating roller peel test setup

(Glass fibre strip is bonded to a film adhesive layer and finally bonded to titanium strip by Magnobond 6367and 6398)[25]

The unavailability of film adhesive in the Sri Lanka Air Force was a great issue in this process. The construction of the trim tab was done by two titanium alloy pieces bonded together using film adhesives. Due to the unavailability of film adhesives in the SLAF, a peeled off tab surface was used as a solution. Accordingly, after doing some surface preparation, the glass fibre strips (rigid adherend) were bonded by available adhesives. In that way, the actual failure condition was simulated and the test performed on the same. The results found are as follows.

Table 3: Peel load and maximum peel strength of presently used adhesives

Type of Adhesive bonding	Peel Load (N)	Maximum Peel Strength (N/mm)
6367and Film adhesive interface	28	28 N/25mm = 1.12N/mm
6398 and Film adhesive interface	30	30 N/25mm =1.2N/mm

4.2 Differential Thermal Analysis

To evaluate the properties of adhesives used, Differential Thermal Analysis was carried out in order to determine the glass transition temperature of the same. Here, Magnobond 6367 and Magnobond 6397 was tested and the glass transition temperatures were obtained. Further, the same test was used to test for the unavailable film adhesives by obtaining a very small quantity from the edges of the new trim tab. The results of DTA for three adhesives are as follows.

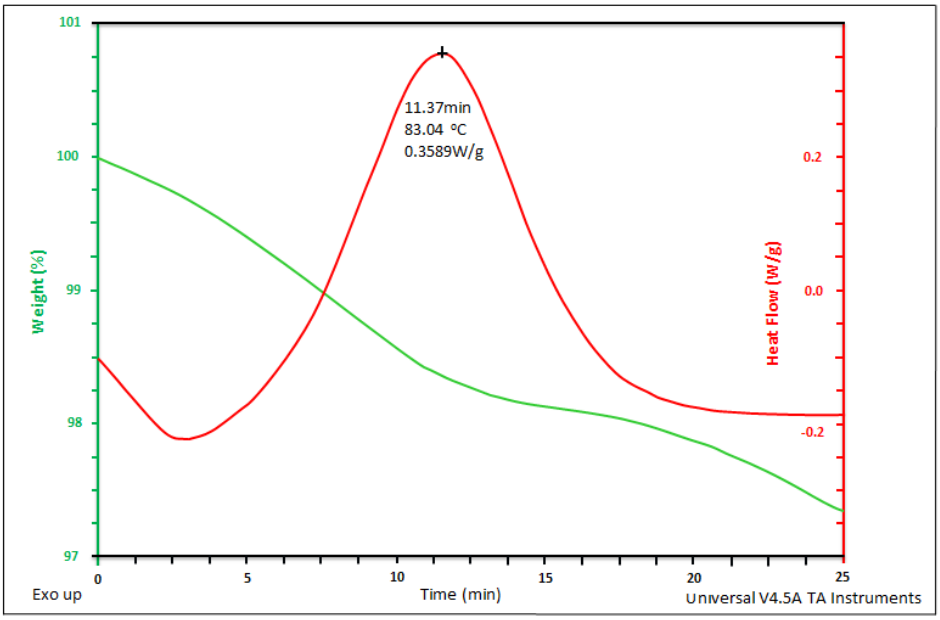

Figure 13 : DSC curve and glass transition temperature (Tg) for Magnobond 6398

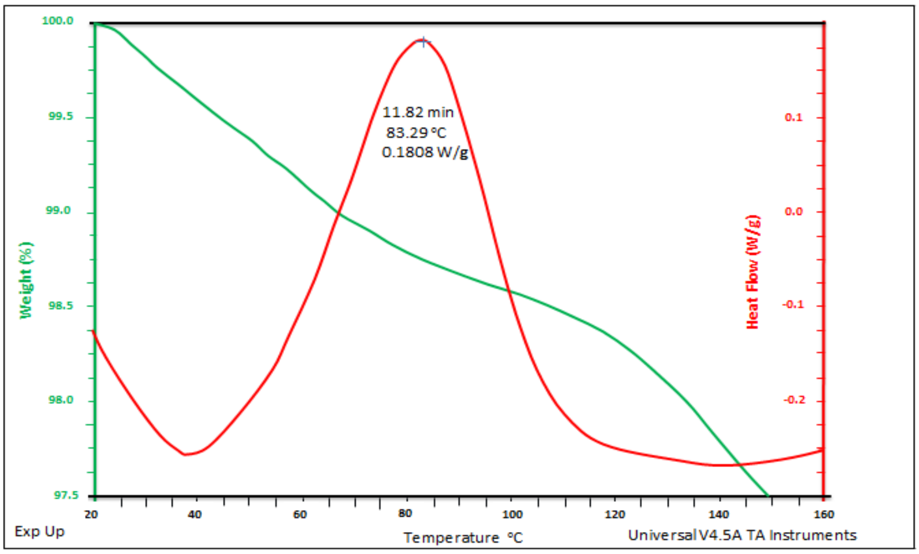

Figure 14: DSC curve and glass transition temperature (Tg) for Magnobond 6367

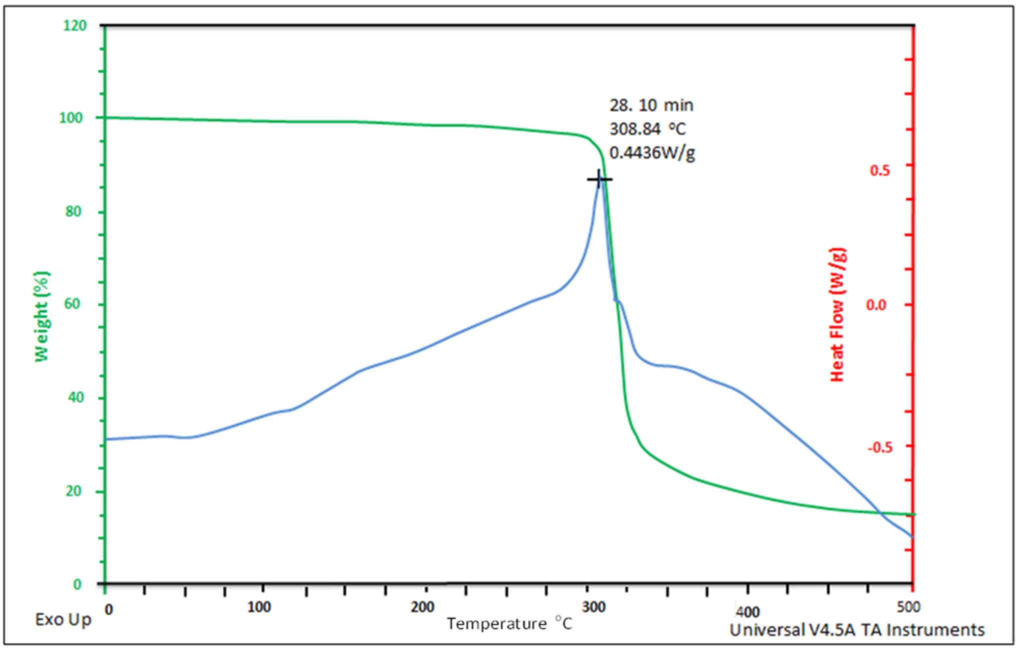

Figure 15: DSC curve and glass transition temperature (Tg) for film adhesive

Table 4: Glass transition temperature of adhesives

Adhesive Type	Glass transition temperature (Tg)
Magnobond 6367	83.29°C
Magnobond 6398	83.04°C
Film Adhesive	308.84°C

4.3 Computational Fluid Dynamic (CFD) Analysis of trim tabs

During the Computational Fluid Dynamic (CFD) analysis, three trim tabs were designed using SolidWorks software tool while the aerodynamic loads which are subjected during the rotation of the blades were simulated. Simulation has been carried out considering the maximum load conditions applied on the blade. As per the CFD analysis, the following are the final results for the tab at 0 and 5 degree.

Station	Without tab	With tab 0 degrees	With tab 5 degrees downwards	Maximum Load on tab (N)
Station 1	8.9416	7.63156	12.1082827	3.1666827
Station 2	71.1711	60.381	91.186294	20.015194
Station 3	113.734	96.0567	147.806111	34.072111

Table 5: Load on tab for 0 and 5 degree

4.4 Fracture mechanism

A failed corner edge of the trim was subjected to a fractography analysis. The analysis consisted of visual observation on the exposed fracture surfaces and selected areas of interest were inspected using optical microscopy. finally, the fracture surfaces were characterized using Scanning Electron Microscope (SEM). During the SEM inspection of 50x, 250x and 1000x magnification, the obtained images are as follows.

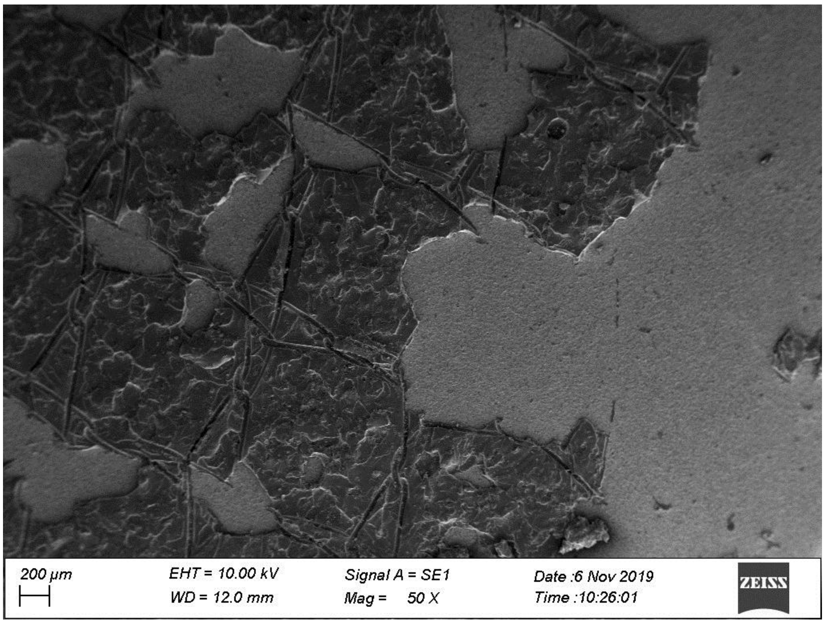

Figure 16: SEM fracture initiation surfaces of the trim tab (50X)

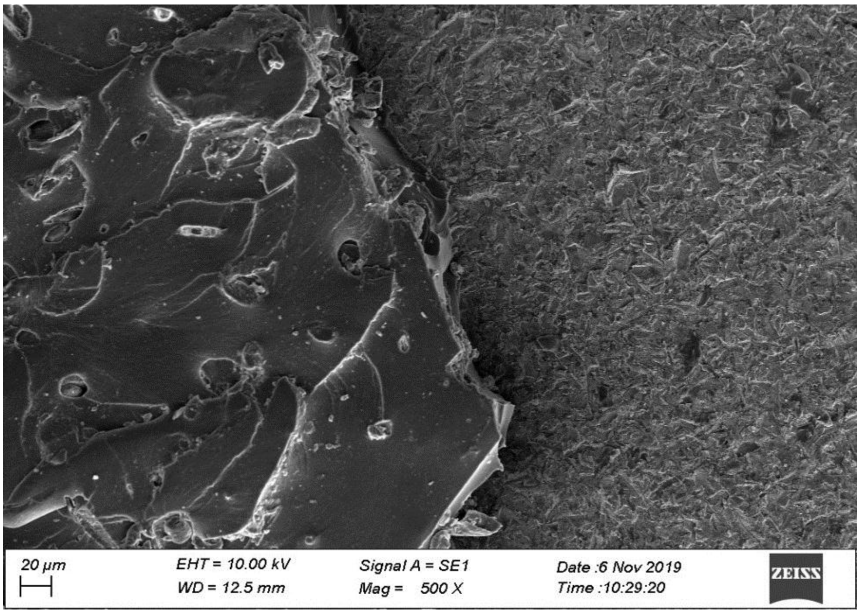

Figure 17: SEM fracture initiation surfaces of Trim tab (500X)

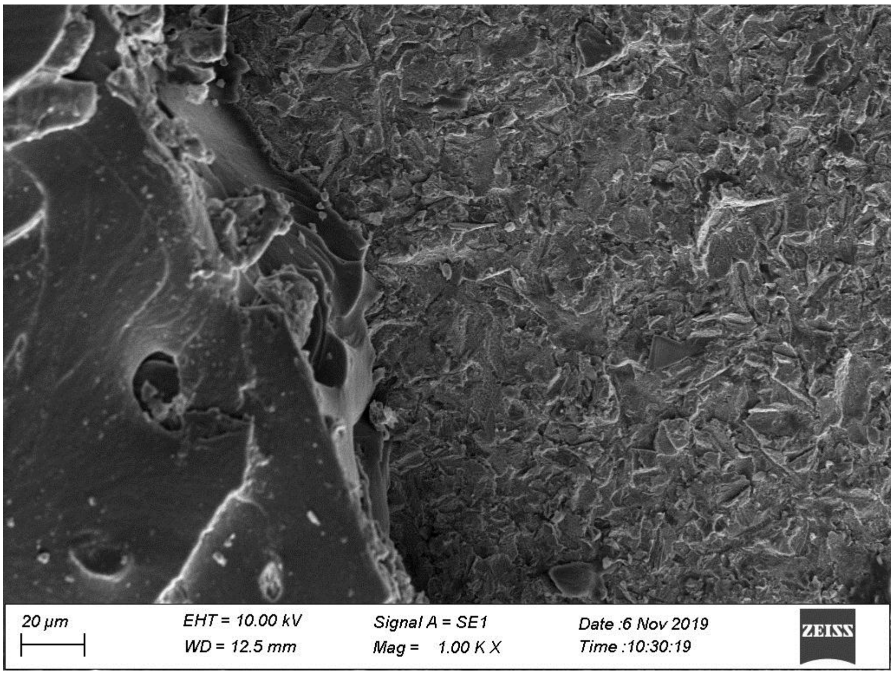

Figure 18: SEM fracture initiation surfaces of the Trim tab (1000X)

An analysis was further carried out to inspect the peeled surface of tab which was formed by peeling off manually. This is a layer of film adhesive which was presented at both removed metal surfaces. The purpose of this was to have an idea about the adhesion properties of film adhesive which has shown a great adhesive bonding strength as per past experiences.

As per the fractography analysis, it can be clearly seen that film adhesive has good adhesion properties with the metal surface, since the failure is cohesive within the adhesive material itself and not at the metal and adhesive interface.

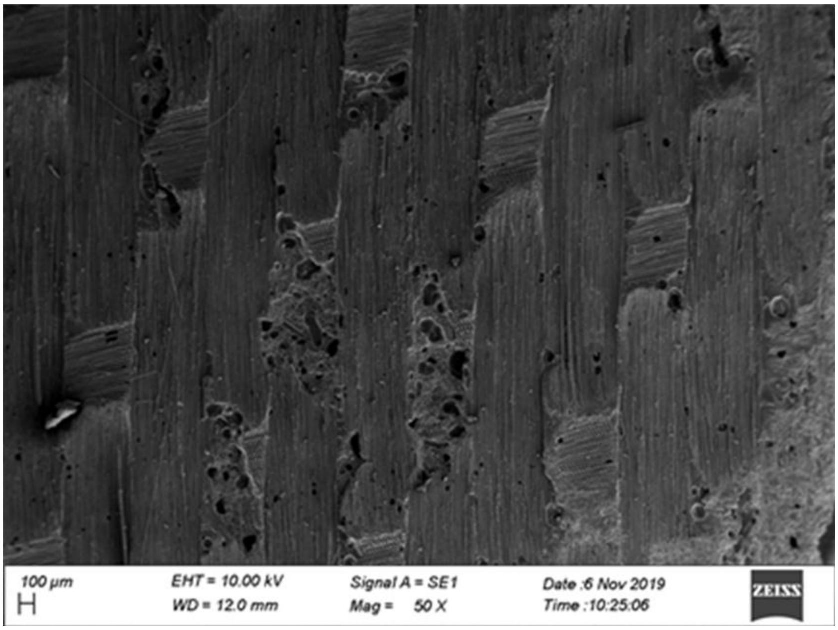

Figure 19: SEM fracture surface of film adhesive (50X)

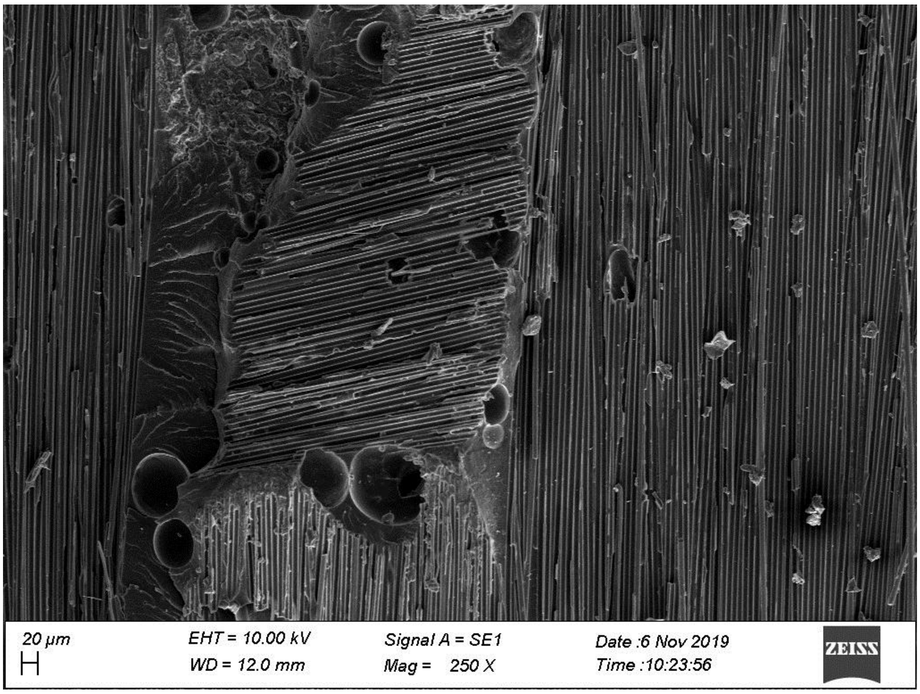

Figure 20: SEM fracture surfaces of film adhesive (250X)

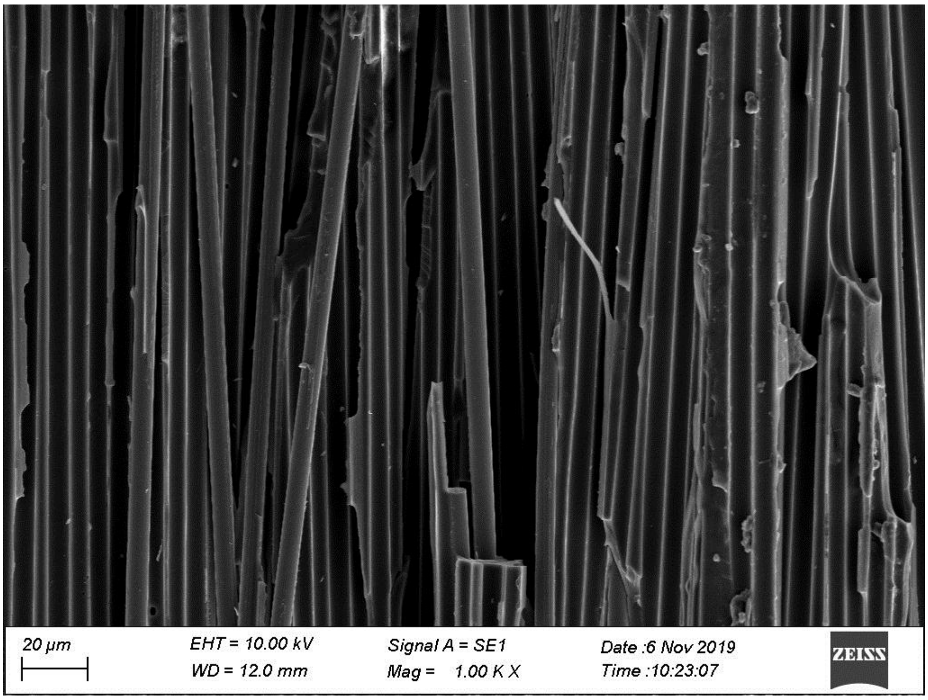

Figure 21: SEM fracture surfaces of film adhesive (1000X)

This research focused on investigating the problem of trim tab failure and associated issues. In this regard, the following salient points were found:

a. As per the findings of the technical data gathered for this matter, it was revealed that the failure rate was initially low and subsequently improved extensively. According to the research findings, after the replacement of new adhesives during the maintenance, this failure of trim tab accelerated and bought to light other related incidents which have also come to the forefront. This has resulted in monetary wastage and a depreciation of the life of the blade. Therefore, it is evident that this study is a relevant and timely one which has not been given due attention during the long period of operation the Bell 412 blades have been in use in the SLAF. This issue is also a problem of safety which has not been duly recognized by the maintenance crew. The only remedial action which has been taken up thus far is the replacement of the trim tab after the observation of the failure of these trim tabs.

b. When a trim tab failure was observed, it is noted that it began from the periphery, developing gradually to the inside of the blade. On inspecting the edges, this investigation revealed an adhesive failure on the trim tab surface. The same surface was subjected to a SEM analysis where the results confirmed that this is a failure of the adhesive. Further, the results obtained from the CFD analysis also confirmed that stress distribution was more pronounced at the periphery.

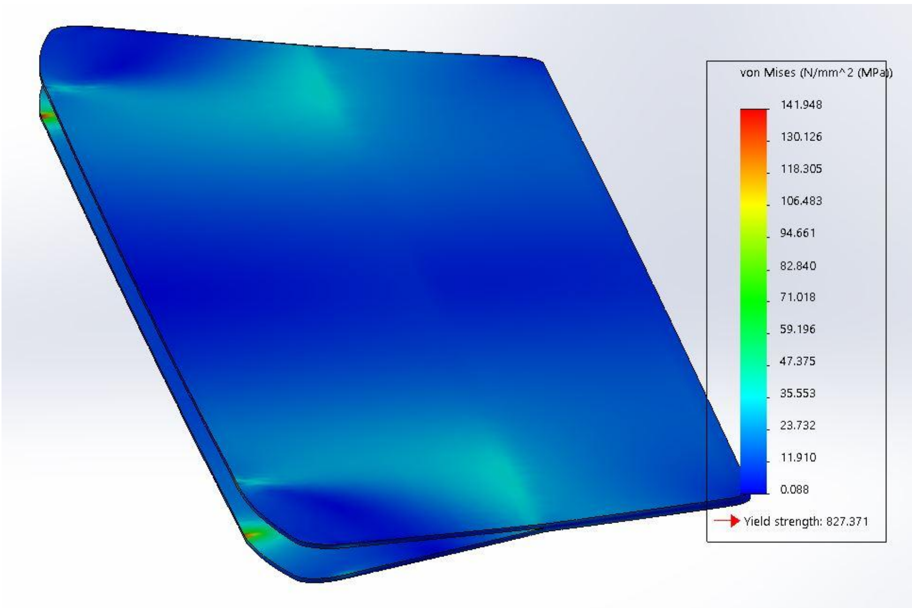

Figure 22: Stress distribution on the trim tab

Table 6: Loads on tab

Load description	Load (N)
Average load on the trim tab	10N
Maximum load on the corner edges	140 N

c. According to the stress distribution data, it is observed that two points on the leading edge of the tab have high-stress concentration and these areas directly affect the initial de-bonding of the tab. Further, as per past records, it was found that initiation of the de-bonding starts at the corner edges of the tab and subsequently develops to the surrounding areas on it. Therefore, this design is critical to the failure of the tab on the blade.

d. The findings of these results is evidence that the initiation of failure occurs due to an excess of adhesive bonding strength and therefore the investigation proceedings were narrowed down to investigate the adhesive bonding strength of the adhesives used at present. Accordingly adhesive testing methods were investigated and floating roller peel test was best suited for this experimental setup.

Floating roller peel test was performed on the adhesive bonded trim tab samples and it was found that the peel load for the Magnobond 63637 and Magnobond 6398 were nearly 10 N. After observation of the above results, a further study of this issue was conducted. It was found that the tab provided by the manufacturer has an additional construction on the trim tab. The case study was focused on determining the bonding strength between the titanium tab and glass fibre strip. The subjected adhesives (Magnobond 63637 and Magnobond 6398) was tested only with metal and glass fibre bonding only. However, the titanium alloy trim tab has an additional film adhesive layer bonded to itself and during the tab bonding the adhesives (Magnobond 6367 and Magnobond 6398) is bonded to the glass fibre from one side and the film adhesive layer is bonded from the other side. Therefore the experimental setup was changed to simulate the same.

However, the unavailability of film adhesive in Sri Lanka Air Force was a challenge in performing this test. The construction of the trim tab was done by two metal strips bonded together by film adhesives. As a solution, a used tab which was removed from a blade (in to the same two pieces) and a layer of film adhesive was placed on the tab surfaces. Accordingly, after doing some surface preparation, glass fibre strips were bonded by available adhesives. In this way, the actual failure condition was simulated and the test performed on the same.

Figure 23: Peeled off tab piece

The root causes for the failure of trim tabs were mainly two loads which can be considered as aerodynamic loads and tab adjustment loads which are applied on the ground. Aerodynamic loads were simulated using software simulation and as per the results, significant loads are applied on the three tabs. According to the results obtained, the inboard tab is subjected to the lowest load and outboard tab was subjected to the highest load. When the tab increased its angle, the load on the tab further increased. As per simulated results, the load on the tab is applied in a downward direction and it affects the tab's removal at the edges. Further, during ground adjustments of the tab, nearly 10 N was applied on the tab to bend them to desired angles. As per load on the tabs, they underwent a fatigue loading condition and the failure of the trim tab is then initiated.

With regard to the tab bonding process, the following steps were carried out.

a. Surface preparation of film adhesive layer
b. Application of adhesive on both surfaces on tab and blade
c. Application of hot bonding process 155 – 165 ^{0}F (69 – 74 ^{0}C)[26] for 2 hours
d. Curing the bond

During the bonding, hot bonding process is commonly used, including at the Rotor Bay, and special attention was paid in this process to investigate the root causes of failure. As per the results obtained for the Magnobond 6367 and Magnobond 6398, glass transition temperature was 83.29°C and 83.04°C respectively. However, as per OEM's recommendations, hot bonding range is to be maintained to 155 – 165 ^{0}F (69 – 74 ^{0}C) temperature. Here, it can be seen that this temperature has reached nearly 89% of glass transition temperature and due to errors associated with the temperature monitoring process, this value can exceed beyond that percentage of glass transition temperature. Therefore, this affected the bonding strength of Magnobond 6367, Magnobond 6398 and the properties of the same can be adversely affected. However, in this operating temperature, film adhesives reached to nearly 23% of glass transition temperature and this did not affect the bonding strength of it. Further, glass transition temperature provides a good indication of the cross-linking of adhesives and gives us an indication of the bonding strength. As per findings, it can be seen that film adhesive had the highest cross linking state in comparison to the other two adhesives. (Magnobond 6367 and Magnobond 6398).

Further, due to friction losses on the blade, the temperature of the blade can also be increased to a considerable amount. This greatly affects the bonding strength and durability of the same. During maintenance, it was found that due to higher outer temperature, tabs are more prone to de-bond and failures could be seen frequently.

In addition to this, due to the dynamic fatigue loading condition, tabs are susceptible to de-bond from blades. However, the above adhesives do not have the details of thermal expansion coefficient values and variations of thermal expansion coefficient. Both adhesives which were bonded together (Film adhesive and Magnobond 6367/6398) had great probability to de-bond at the bonded surfaces.

The effects of weather condition changes also influenced the bonding strength and exposure of bonding to the environment, water absorption, reaction of chemicals with adhesives also deteriorated the bonding strength of the same.

As per simulated results based on the trim tab design on the blade, stress areas are shown as following and the highest stress is governed by the outboard tab and lower at the inboard tab. Therefore, there is a high probability of failure occurring at the outboard tab and the least probability of failure, at the inboard tab.

Tab Station 1

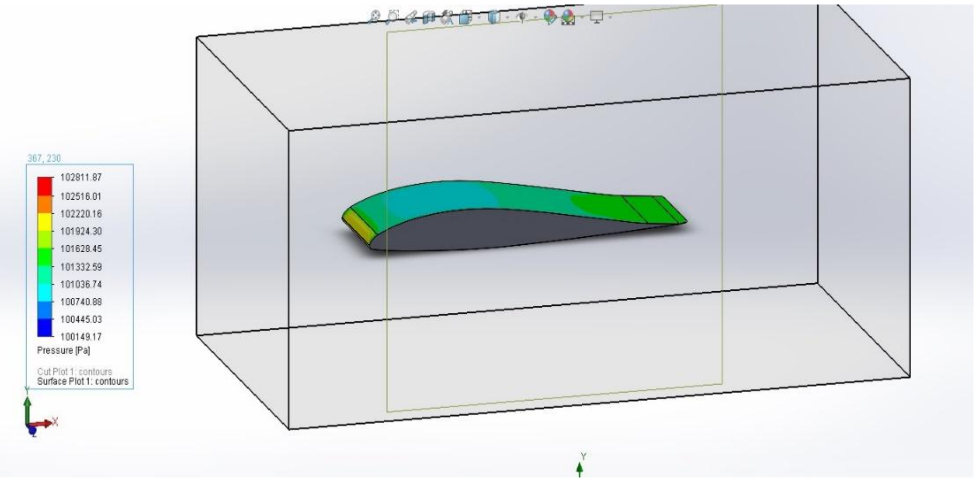

Figure 24: Stress distribution over the tab surface station No 01

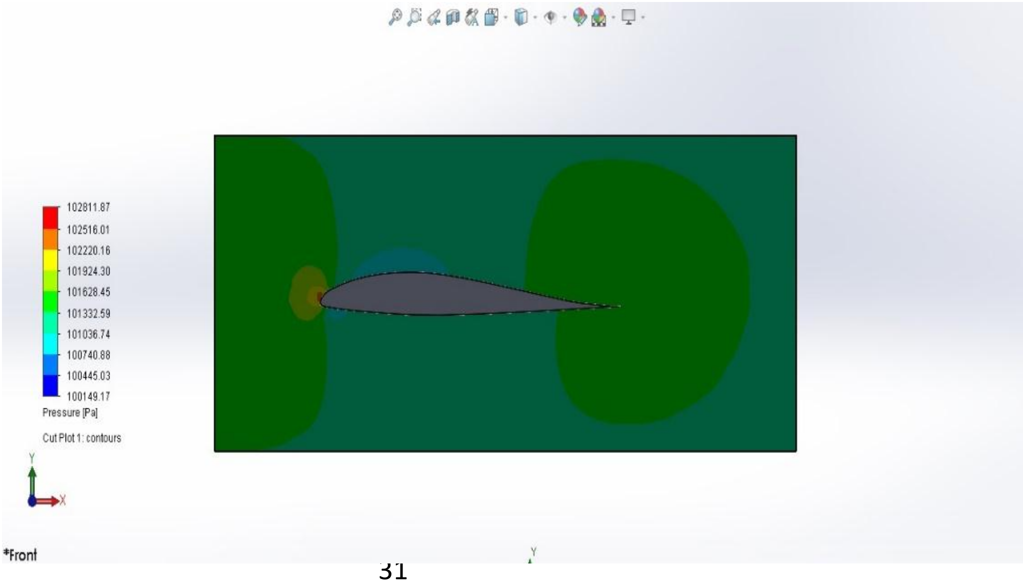

Figure 25: Lift distribution over the aerofoil cross-section station no. 01

Tab Station 2

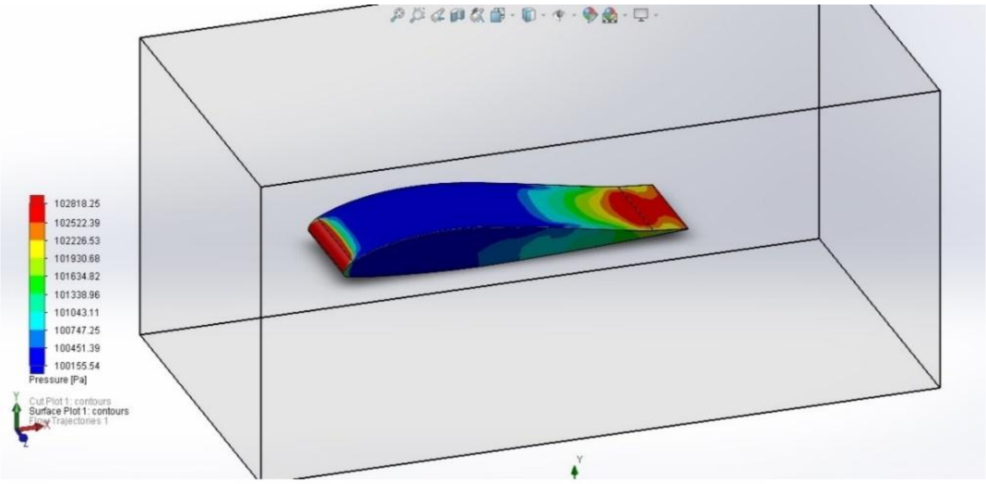

Figure 26: Stress distribution over the tab station No. 02

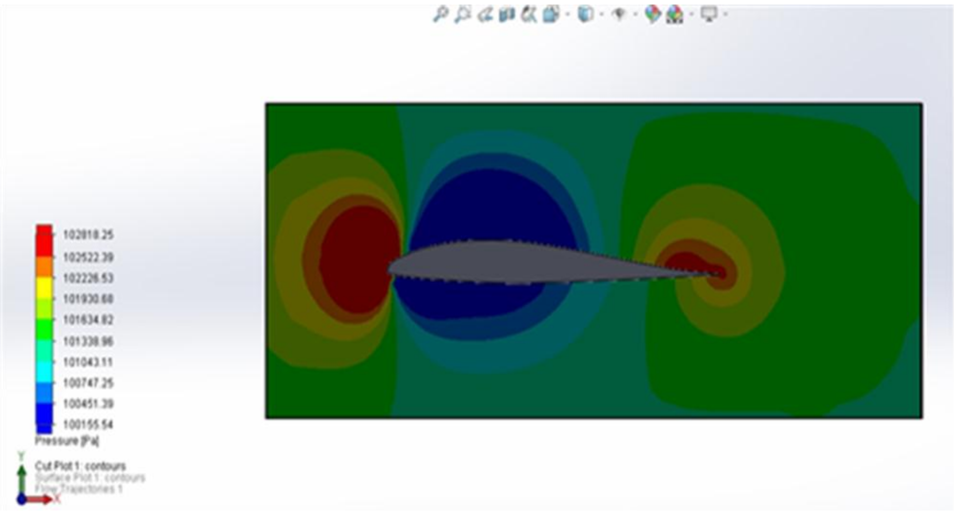

Figure 27: Lift distribution over the aerofoil cross-section station no. 02

Tab Station 3

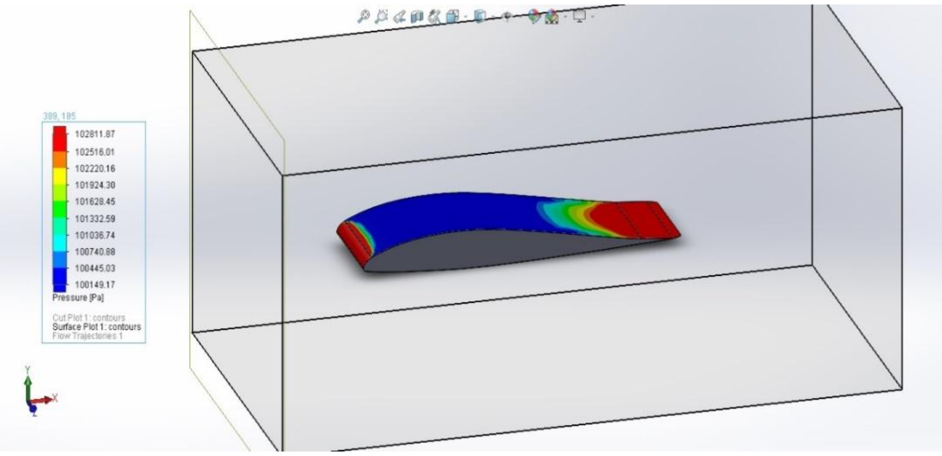

Figure 28: stress distribution over the tab station no. 03

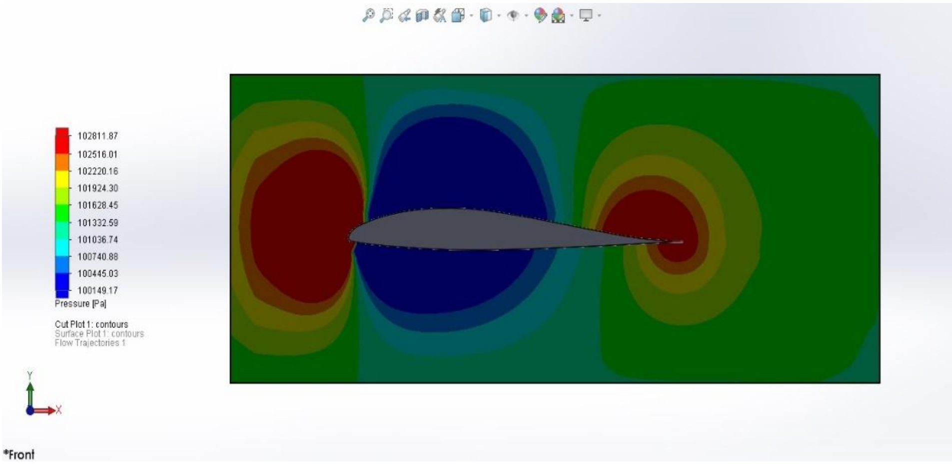

Figure 29: Lift distribution over the aerofoil cross-section station no. 03

According to the stress distribution findings, maximum stresses applied on the trim tab is higher than the bonding strength results obtained from the floating roller peel test. Therefore, there is a great possibility of the bond failing between the trim tab and the blade. Further, it was proved that the load on the trim tab occurs to peel the tab off from the blade and it is a sufficient supportive load to cause the failure. This stress concentration was observed due to the design failure inherent in itself and the same was proved the by this CFD analysis. Further, the study was extended to change the design of the trim tab and as per the new design trim tab, the stress distribution of the tab was as follows. It is noted that in this design, tab bonded surface area is kept as constant and only the tab bonded area contour was changed.

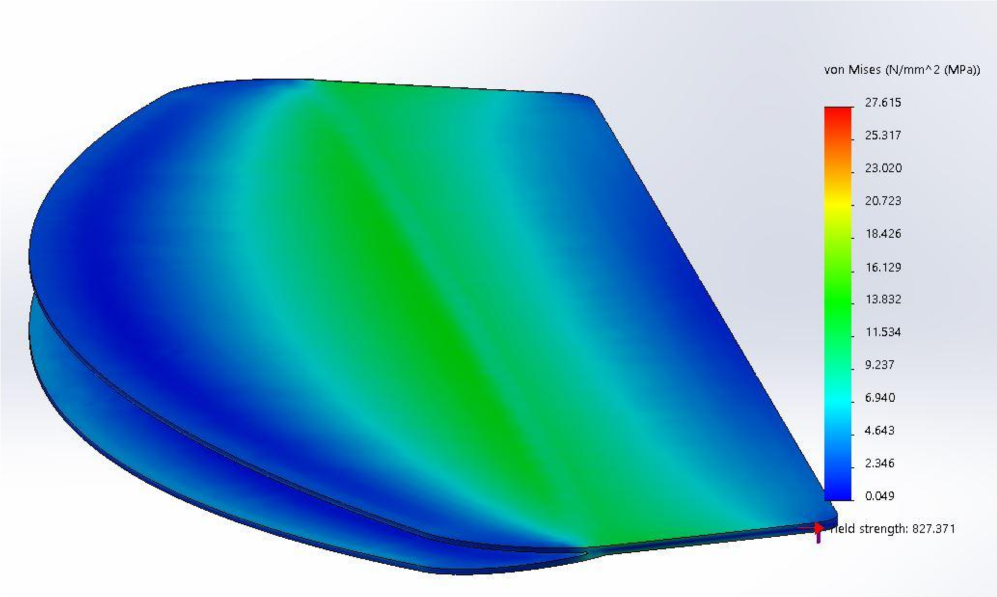

Figure 30:Stress distribution over the modified tab

As per the CFD analysis, the following are the results for the modified tab.

Table 7: Maximum load calculation without tab and with tab

Station	Without tab	With tab 0 degrees	With tab 5 degrees downwards	Maximum Load on tab (N)
Station 1	8.9416	7.63156	12.1082827	3.1666827
Station 2	71.1711	60.381	91.186294	20.015194
Station 3	113.734	96.0567	147.806111	34.072111

Table 8: Load calculation on the presently used tab and modified tab

Station	Tab (MPa)	Modified Tab (MPa)
Station 1	11.980	0.753
Station 2	141.948	6.940
Station 3	241.632	12.293

After the application of a maximum resultant force on the tab, the following distribution of stress can be seen. It is clearly visualized that the stresses on the modified tab had significantly reduced with the new tab design.

The impetus of this research was to put forward a suitable adhesive material to overcome this issue but this objective was unachievable due to time constraints. However, as per obtained results, it is evident that the adhesives currently used should be discontinued from application and it is critical to seek another adhesive material solution which is far more suited as a replacement of the same. In addition, based on the results obtained, the experimental process followed up in this research can be successfully utilized to evaluate its adhesive properties for the intended purpose.

As per the fractography analysis, it is evident that it has undergone an adhesive failure in between the two adhesive-bonded surface on the tab and it shows poor adhesion characteristics in between the two adhesives.

These results highlight a critical area latent in the maintenance practices and the same results are brought forward to the OEM’s attention to seek a more suitable adhesive application for the trim tab. This is a pioneering study to use manufacture recommended adhesives with a proper analysis for use for the relevant application by considering its operating conditions and manufacturer recommended maintenance status.

Finally, to overcome the trim tab failure, following remedial action can be taken.

a. As already discussed in the above, the replacement of adhesive with the recommendations of OEM can be considered. At present, it is not possible to use film adhesive for maintenance at the blade repair facility at SLAF. However, it is proved that it carries excellent adhesion properties in comparison to the other two adhesives which are used at present. Further, film adhesive has proven its capability in terms of adhesive characteristics in the practical experience gained over the years. Therefore, it is planned to forward these findings to OEM to prompt further discussion on the usage of film adhesive at the SLAF facility or request for a new adhesive which can be successfully used for this bonding. As mentioned earlier, this study can be similarly utilized for any new adhesive which is intended for this purpose.

b. Further, modified trim tab design was given as a remedial solution to minimize the high stress concentrated area existent in the present design. As the current tab design promotes the failure of the same and this modified design will be valuable in designing the trim tab for future use. This trim tab design will also be submitted to OEM.

c. As the next solution, it can be noted that the tab bonding process also can be changed as a remedial solution for the same. In the construction of the glass fibre blade, 7-8 layers of glass fibre cloths were used and as a remedial measure before bonding the trim tab, the two top glass fibre layers can be removed (only limited to the tab and nearly 1.5'surrounded area around the tab bonded surface) and the tab can be bonded to the blade. Further, after the curing process, it is possible to put two layers of glass fibre cloths which close the entire bonded surface on the glass fibre blade. This arrangement will help to better distribute the stress that occurs on the tab in a larger area, on to the glass skin and the failure can be minimized accordingly.

d. Further research was done based on the formation of a smooth and rough thin film on glass fibre by using sol-gel technique. In this method substrate is dipped in a composite sol-gel solution and a thin film of Tio_2 on the fibreglass is obtained. The depositing of film was done using the solution of Titanium (IV) iso-propoxide as sol-gel precursor and this will allow it to develop a layer of Tio_2 glass fibre. By using this technique it is possible to have a metal to metal bonding with the selection of a suitable adhesive for the same. Film adhesive is a good adhesive to be used for metal to metal bonds and has proven its performance with metallic surfaces. Therefore, this is also another remedial solution to mitigate this failure on the trim tab and can extend its life on the blade.

5. Conclusion

This research was primarily focused on investigating the failure of the Bell 412 trim tab which was observed for nearly three decades in the maintenance history of the Bell 412 main rotor blades. As per the findings, it is clearly evident that this issue is not exclusive to SLAF but also affects more than 50 countries in the world where this aircraft is operational. There was no dedicated study undertaken previously thus far and these findings will set a precedent which is relevant to others around the world. Therefore, the failure of trim tabs was studied to solve the issue with a suitable material application and new trim tab design. The objectives were set accordingly.

In the initial findings which were based on assimilated historical records of failure, the pattern of failure of the trim tab and initiation of failure was analyzed. Based on the results, the failure of the adhesive was identified. As per the defined objectives research was conducted initially to identify the root causes for this particular failure. According to the findings, the loads on the tabs which are applied as ground loads and aerodynamic loads are causes for the failure. The experimental setup proceeded to investigate the bonding strength of trim tabs given from the floating roller peel test. Further, as per the results obtained from the CFD analysis, it was highlighted that the loads on the tab station 1 and station 2 are lower than the bonding strength of the adhesives. Further, the loads on the tab station 3 is higher than the bonding strength of adhesives. Therefore, the tabs at tab station 3 have a higher occurrence of failure of and practically, the same has also been experienced. When the adhesive bonding strength between metal to fiber bonding was analyzed, Magnobond 6367 and Magnobond 6398 adhesives revealed a very low bonding strength. After further investigation, it was found that the above two adhesives which are being used at present are bonded to the trim tab by a layer of Film adhesive. This arrangement was re-developed to assess the real bonding strength between the tab and the rotor blade. The results of the bonding strengths of each adhesives gave a better idea about the adhesive properties. These insights can be used to develop a new adhesive for this intended purpose. Thereby, as depicted in the objectives the bonding strengths were successfully analysed during the research.

As per the objectives, by carrying out the unique experimental setup followed here, the failure of trim tabs and reasons governing this particular failure were successfully identified. Further, in the Computation Fluid Dynamics (CFD) simulation, it was highlighted that the corner edges of trim tabs are highly stress concentrated areas and this is highly likely to fail the trim tabs. The loads on these concentrated area are approximately 3-4 times higher than the bonding strengths of these adhesives. Thereby, the design itself promotes the failure of trim tabs and this study was able to prove the same.

As per the predefined objectives, the failure of trim tabs were successfully identified through a unique set of experimental approaches. Throughout the whole research, the following factors were revealed.

1. As per OEM's recommendations, film adhesive was restricted for the maintenance at the facility of SLAF. However, data from records showed the durability of film adhesive bonding is about 1000 hours on average while for the new adhesives, it is limited to 150 to 200 hours. The same was proved with the Differential Thermal analysis results. Thus, it can be concluded that the new adhesives introduced by OEM is not a feasible solution for the bonding of the trim tabs.

2. According to OEM's instructions, the presently used two adhesives are designed to use for the bonding of glass fibres and metal surfaces. However, in this situation, the bonding surfaces are glass fibre blade skin from one side and film adhesive surface on the other. Therefore, this adhesive is not suitable for this application. The OEM has used a film adhesive layer on the tab to have a proper bonding at the metallic surface. But when it bonded with Magnobond 6367 or Magnobond 6398, a durable bonding was inexistent. Based on the data of this failure, it was proven that failure initiation occurs at the two adhesive interface surface. Thereby, it can be recommended that this bonding arrangement cannot be further used for this purpose.

3. After the observation of this failure on several occasions this matter was brought to the attention of OEM and the only remedial solution offered was the replacement of tabs after the failure. But based on the research results, it can be stated that this replacement option as introduced by the OEM may be considered only after assessing the financial benefits of the same.

According to the research findings, it is possible to consider research outcomes which are helpful to extend the life of the blade. When considering the blade inventory of Bell 412, it deals with more than 150 tabs on blades. If one-time tab replacement is considered, it will amount to USD 300,000.00 (Rs 54,000,000.00). Further, if other associated costs are considered, it will further increase the cost of repair. Therefore, addressing this matter will result in cost savings for the SLAF. Further, it is planned to produce these research findings to the attention of the manufacturer and to obtain a possible solution. This will be advantageous for all other operators globally.

According to the research findings, it can be further stated that adhesive bonding which included more than one adhesive will not be a good solution (sandwich arrangement of adhesive bonding) for long term durability of the same. When it more than one adhesive is involved, parameters like thermal expansion coefficients, differences in bonding strength, surface condition of the partially cured adhesive etc. can impact the long term durability of the bonding.

Therefore, as revealed in this research study, hybrid adhesive bonds cannot guarantee a successful adh esive bond for durable applications. Only one adhesive, which can withstand all the loading conditions and is suited for long term durability, is recommended for application. At present, a higher failure rate is evident due to this matter and only one adhesive (Film adhesive AF 163 2K) which is used at the manufacturer recommended blade repair facilities has shown its capability for the intended application.

As per the results of the Differential Thermal analysis, it has been proved that the Magnobond 6367, Magnobond 6398 have lower Glass Transition Temperature (Tg) than the film adhesive and showed lower performance characteristics for the intended bonding purpose. Considering its working temperature, it has a great possibility of exceeding or reaching to the Glass Transition Temperature and accordingly affects the bonding strength and thereby also causes a failure to bond. Therefore, before the use of adhesives for the specific application which involves the temperature parameters, it is essential to check the adhesive properties concerning the glass transition temperature. This research was able to understand the adhesives presently used and its performance with the existing working temperature, which was introduced by OEM. In this method, it was able to identify the possible causes for the failure and this experimental procedure can be extended to any other adhesives and can be used to determine its properties and possibility of use for the same aspect.

To compare the failure loading condition, CFD based simulation was carried out and as per the CFD results, the areas concentrated with stress on the tab is extensively higher than the bonding strength of tabs and therefore this load can be considered as a load which drives the failure of trim tabs. As discussed in the above discussion, this can be exacerbated with the fatigue loads due to other external factors like environmental conditions of the blade which is operated, wrong bonding practices done by the operators etc. Therefore, it is recommended to OEM to reconsider this design to ensure the long term durability of the tab on the blade.

During the research, the failure of trim tab was identified through a systematic approach. However, numerous difficulties were faced due to the unavailability of testing facilities and materials (Film adhesive- AF 63 2K). These test results were actually obtained from the experimental set up and based on the same, the research outcome was finalized. However, with the original materials and test equipment, this results may slightly vary with the observed readings.

Finally, the remedial measures which could be taken to mitigate the failure of trim tabs and extend the service life of the trim tab for long term use were discussed. These research findings will be forwarded to the attention of OEM and necessary actions will be taken based on the feedback received from OEM**.** In addition to that in this research it was able to identify the following areas which are to be considered for further studies.

a. During the research it was identified a hybrid adhesive bonded application in the tab bonding process. As per the research study it was found that it is not a feasible solution for a long term durability of any bonded structure. The impact on bonding strength of metal composite structures with the application of hybrid adhesive bonding is a new research are that has to be further considered.

b. In here it was highlighted that the presently available adhesives are not suitable for this application. Hence, it is highly essential to find the suitable adhesive unique for this titanium glass fiber bonding. Further, this adhesive development should be considered for the long term durability and especially for the application of dynamic loads.

c. Adhesive bonded structures widely used in the field of aviation and it is important to see the life assessment of the same with the variables of environmental conditions and operational conditions. Therefore research on life monitoring of adhesive for better utilization with its service life is important

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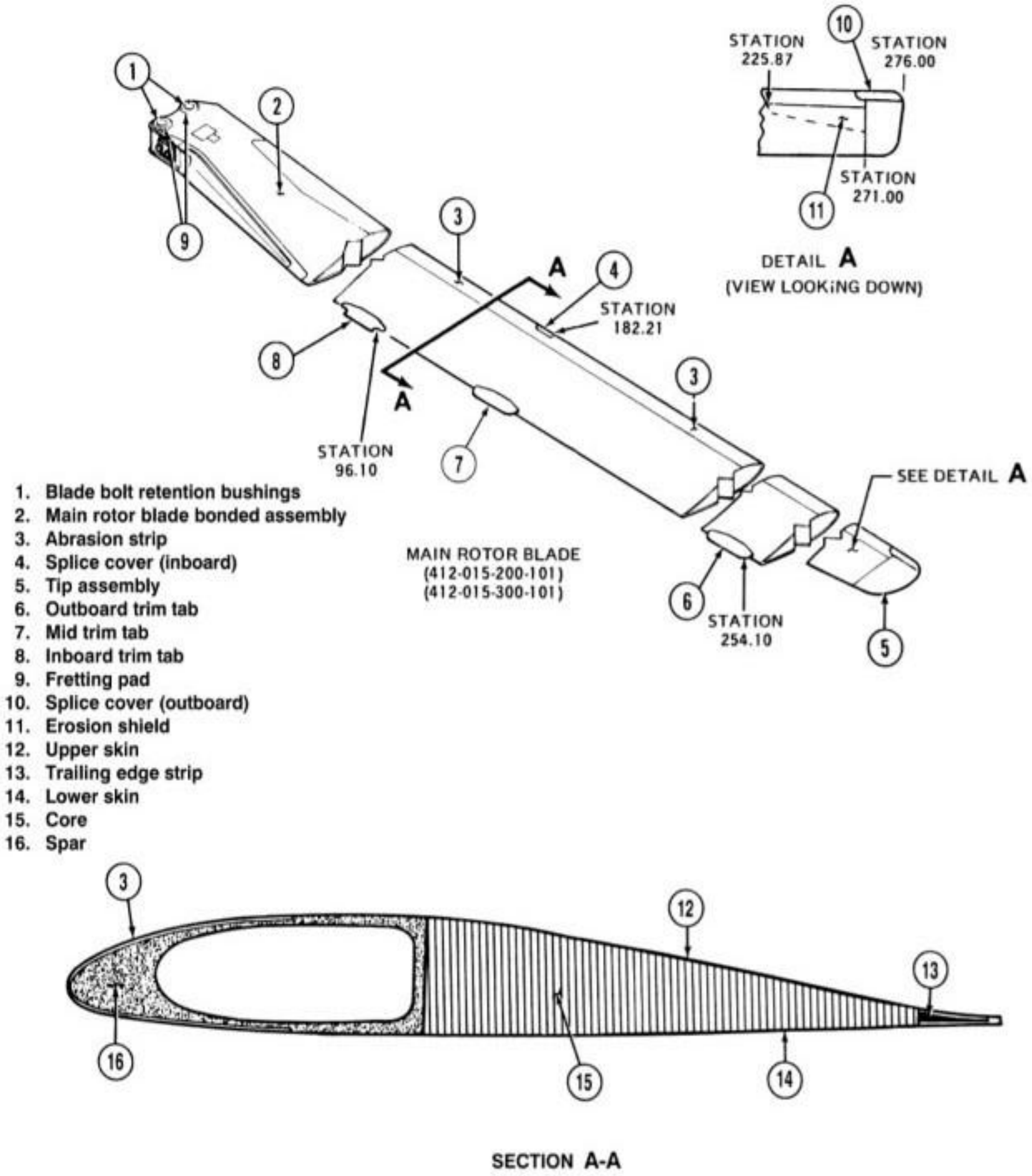
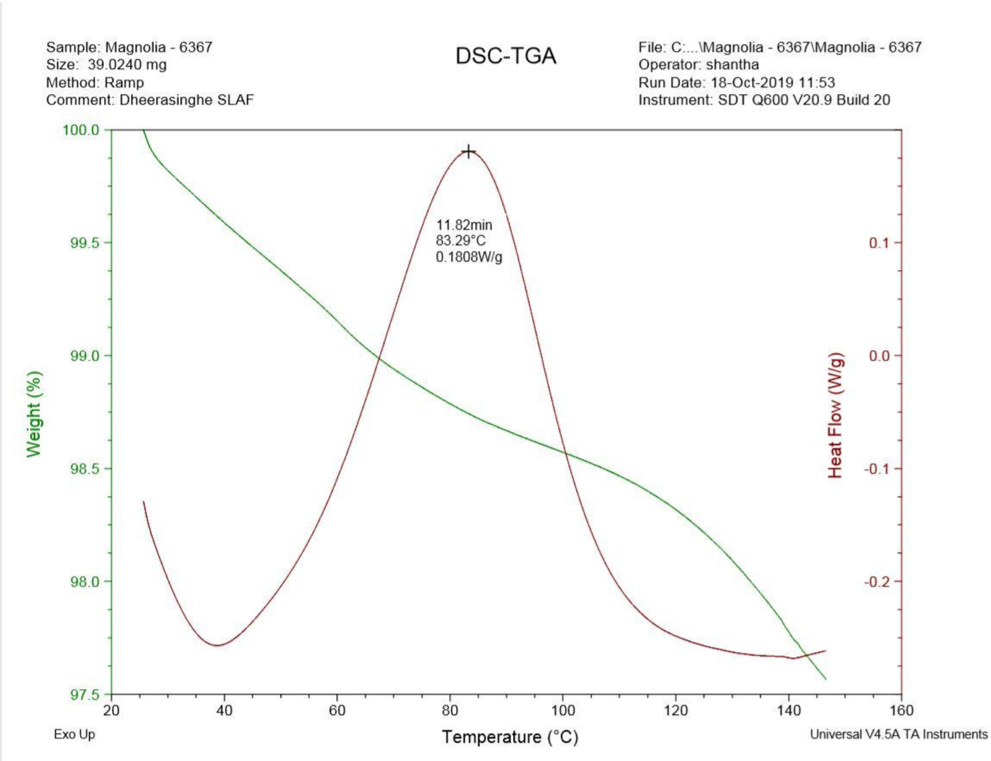
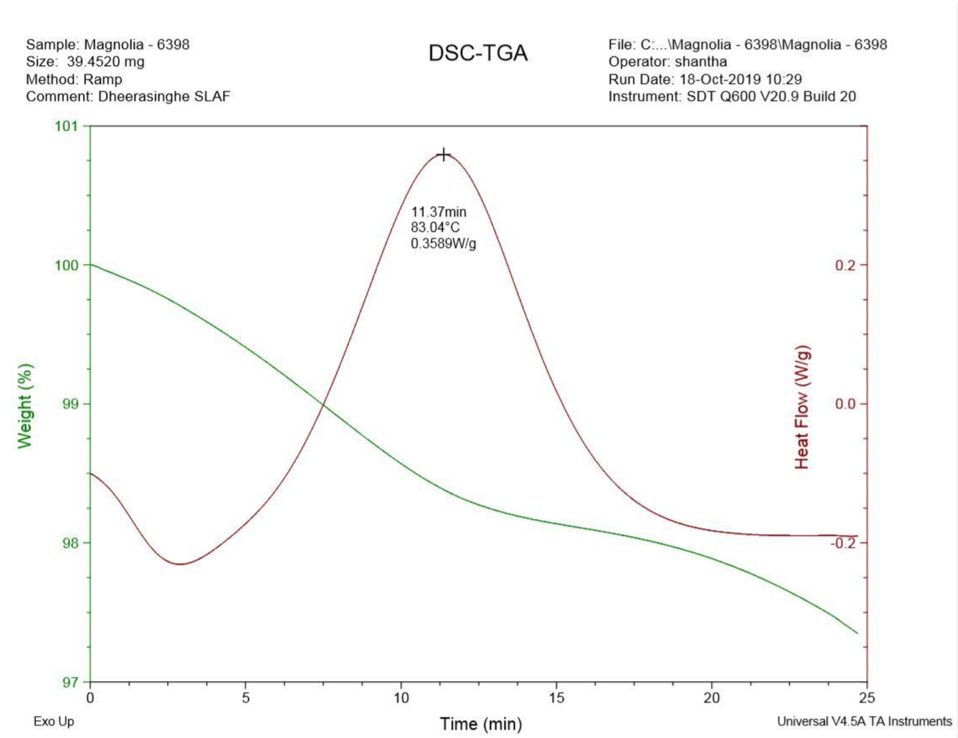
7. Annexes



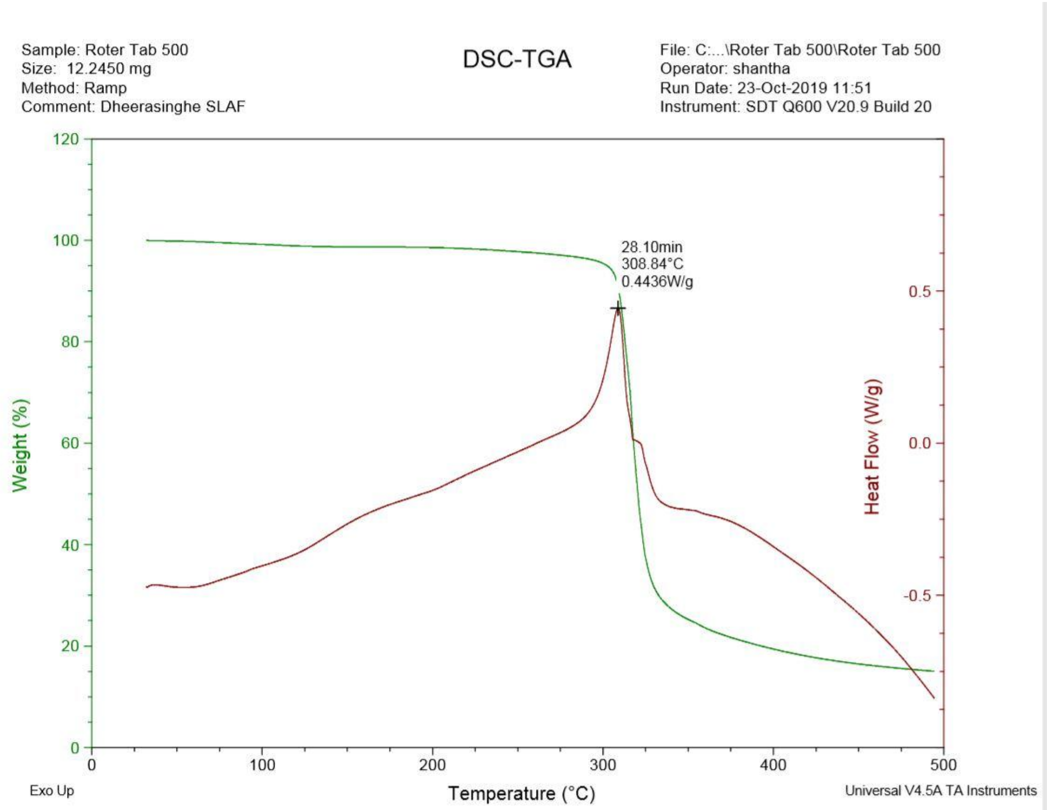
a) The construction of Bell 412 Main Rotor Blade



b) DSC curve for Magnobond - 6367



c) DSC curve for Magnobond - 6398



d) **DSC curve for Film adhesive**

e) **Distance Vs load curve generated by Floating Roller Peel Test**

Table 13-2. Consumable Materials List — Nomenclature Versus Item Number (Cont)

NOMENCLATURE	ITEM NO.	SPECIFICATION	BELL ORDER NO.	ORDER QTY	MATERIAL	CAGE/FSCM/ SOURCE
Glass Cloth, 0.010 inch thick	C-404 S-404	AMS-C-9084, Class 2, Type VIIIB	AMS-C-908418B CL2	3 SQ FT	Any product meeting specification	Commercial
Glass Cloth, 0.005 inch thick	C-560	AMS-C-9084, Class 2, Type III	AMS-C-9084,CL2 TYIII	3 SQ FT	Any product meeting specification	Commercial

BHT-ALL-SPM

Bell Helicopter A Textron Company

Table 13-3. Alternates for Bell Helicopter Textron Adhesives (Cont)

BELL SPEC (ITEM NO.)	ALTERNATE	CURE TEMP	CURE TIME	CURE PRESSURE	STORAGE LIFE	PRIMER
299-947-121, Type I (C-362)	FM 53	260 to 290°F (127 to 143°C)	60 minutes minimum	40 PSI (276 kPa)	180 days below 0°F (-18°C)	BR 53
	FM 87	260 to 290°F (127 to 143°C)	60 minutes minimum	40 PSI (276 kPa)	180 days below 0°F (-18°C)	BR 127
	AF 163-2K	260 to 290°F (127 to 143°C)	60 minutes minimum	40 PSI (276 kPa)	180 days below 0°F (-18°C)	EC 3924B

Table 13-3. Alternates for Bell Helicopter Textron Adhesives (Cont)

BELL SPEC (ITEM NO.)	ALTERNATE	CURE TEMP	CURE TIME	CURE PRESSURE	STORAGE LIFE	PRIMER
299-947-099 (C-313)	Araldite AV1258/ HV1258	Room temp or 145 to 180°F (63 to 82°C) (alternate)	24 hours or 30 minutes (alternate)	Firm contact	12 months at 40 to 80°F (4 to 27°C) or 18 months below 40°F (4°C)	None
299-947-100, Type I, Class 6	EC 3448	225 to 300°F (107 to 149°C)	55 to 65 minutes	Firm contact to 10 PSI (69 kPa)	180 days below 0°F (-18°C)	None
299-947-100, Type II, Class 2 (C-317)	Magnobond 6398	Room temp or 190 to 210°F (88 to 99°C) (alternate)	5 to 7 days or 55 to 65 minutes (alternate)	None or firm contact to 10 PSI (69 kPa) (alternate)	12 months below 40°F (4°C) or 90 days at 40 to 85°F (4 to 29°C) or 60 days at 85 to 100°F (29 to 38°C)	None

Table 13-3. Alternates for Bell Helicopter Textron Adhesives (Cont)

BELL SPEC (ITEM NO.)	ALTERNATE	CURE TEMP	CURE TIME	CURE PRESSURE	STORAGE LIFE	PRIMER
299-947-100, Type II, Class 3 (C-363)	Hysol EA956	Room temp or 195 to 205°F (91 to 96°C) (alternate)	5 to 7 days or 55 to 65 minutes (alternate)	None or firm contact to 10 PSI (69 kPa) (alternate)	12 months below 40°F (4°C) or 90 days at 40 to 85°F (4 to 29°C) or 60 days at 85 to 100°F (29 to 38°C)	None
	Magnobond 6367	Room temp or 190 to 210°F (88 to 99°C) (alternate)	5 to 7 days or 55 to 65 minutes (alternate)	None or firm contact to 10 PSI (69 kPa)	12 months below 40°F (4°C) or 90 days at 40 to 85°F (4 to 29°C) or 60 days at 85 to 100°F (29 to 38°C)	None

f) Specifications of Glass cloths, Magnobond 6367, 6398 & Film adhesive