JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

CHARACTERIZATION OF AEROSPACE COMPOSITE LINERS USING NON-DESTRUCTIVE EVALUATION TECHNIQUES

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Abstract

Composite materials are a type of material that is employed in the production of present and future aeronautical components.This study mainly takes into account High Silica Phenolic ablative material as well as designed ultra high strength steel material. One example is the Maraging steel shell, which is fused inside with an ablative Ethylene Propylene Diene Monomer (EPDM) rubber lining for heat protection. The current work creates and studies 2 kinds of artificial defects: a) 'Delamination' within levels of High Silica Phenolic composite liner while manufacturing and b) 'Debond' between Maraging steel casing and rubber liner interface. The aforesaid faults were non-destructively characterised utilizing various NDE techniques, including radiography testing, infrared thermography, and ultrasonic testing. A comparison investigation is carried out by comparing the outcomes of various approaches and procedures, and the key elements are noted. X-ray radiography is non-contact and non-invasive, revealing delamination/debonds as black lines in the radiographs. Thermography discloses faults as contrasting fluctuation owing to temperature differences, and ultrasonic testing is a connection which has revealed acoustic impedance incompatibilities.

Keywords: High Silica Phenolic ablative material, Delamination, Debond and NDE techniques.

Introduction

The use of composite materials in aerospace and military applications is continuously growing. In the composites industry, various fabrication and processing technologies are evolving. Innovative techniques and procedures are being studied and refined in order to address the problems of production, processing, and fabrication, as well as to give constant input to enhance the operations. These advancements in non-destructive characterization and assessment technologies, as well as their assistance, were becoming unavoidable not just to throughout the development process, but also through the product realisation phase.

The advanced technologies and equipment vary depending on the kind of composite materials and structures. To guarantee that the composite construction was created appropriately, testing is essential. Sufficient examination

that ensures that the element is adequately connected and has the requisite strength while without causing any harm to the part. There are numerous NDE techniques that can be tested.

Fabrication of High Silica Phenolic Composite Liner

The inside body of the engine and aircraft parts must be insulated from hot combustion gases at around 2200 °C. High Silica Phenolic was used as the ablative substance for this application.

Hand lay-up and autoclave curing procedures are used to create cylindrical liners. Fabrication includes the following steps:

Mandrel assembly, Prepreg Layup, Layup Curing, Cure component machining and Machined component extraction

Mandrel Preparation

The filament winding machine is filled with a mandrel. Emery paper is used to polish the mandrel surface. Acetone and wax polish are used to wipe and wash away the mandrel. For simple removal of the cured material, two coatings of high temperature release agent are placed all over the cleansed and de-greased surface of the mandrel. The below table lists the specs for high silica fabric and phenolic resin.

Prepreg Layup and Teflon Inserts (Defect)

Over through the aluminium alloy mandrel, five layers of High Silica Phenolic prepreg are applied. Every layer contains two circular joints. These joints are dispersed on the perimeter of the mandrel in all 5 layers (10 pieces of prepreg) to prevent weak zones in the final product. Each of the ten prepreg pieces has a 10mm overlap. The prepreg measurement is calculated using the mandrel diameter of 273mm. The prepreg width is determined as (3.1415D/2 + 10) mm. To assist the lay-up procedure, the mandrel is retained in slow spin, and a Teflon inserts is placed between the sheets to induce artificial delamination.

Following the application of prepreg sheets to the mandrel, two layers of high tension hoop winding are applied to the element for stabilization. 5mm thickness is achieved by layup and hoop winding (extra thickness is given for machining allowance).

Curing of the Layed Up Component

The laid-up component and mandrel are stored in a vacuum bag. The bag is fitted to the component size to reduce creases. On lay up, the released fabric is coiled, followed by three layers of breather material. This breather-wrapped item is contained within a vacuum bag. A vacuum port is supplied for sucking out air and volatile compounds from the vacuum bag. Curing is done in an autoclave at a pressure of 4 bar, a maximum temperature of 150-160°C, and a vacuum of 0.9.

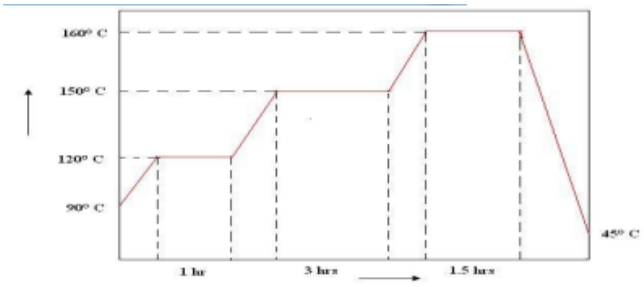

Fig 1: Curing cycle of high silica phenolic.

Machining of Cured Liners

Once curing is done, the cured element in the vacuum bag is removed from the autoclave. De-bagging is complete. Hardness is tested for Barcol as a curing assessment. It will have 60-70 mandrels as well as the cured element installed on the lathe for machining. Firstly, the hoop winding layers were machined out. The outside diameter of the liners is then bent in at least two turns, one rough and one final (finish turning is performed at high speed). Whereas the component is mounted on the mandrel, the outside diameter is determined. Parting occurs once the outer diameter is reached.

Maraging Steel Liners Bonded Inside With Epdm Rubber Bonding Details

The abrasion technique is used to achieve a rough surface finishing on the Maraging steel's inner surface. The inside surface is coated with epoxy resin. The EPDM rubber liner is epoxy resin-bonded within the metal shell and permitted to bind securely. The de-bonding zones are made artificially for the investigation using an external source.

Fig 2: EPDM rubber bonded inside to Maraging steel casing

Following machining and bonding, the two components are evaluated by three separate NDE methods to determine de-lamination and de-bond, including radiography, infrared thermography, and ultrasonic testing.

The primary objective of this work is to concentrate on applying 3 types of NDE techniques for assessing delamination and debonds of Ultrasonic testing, IR thermography and radiography for two components which are Maraging steel casing with Ethylene Propylene Diene Monomer (EPDM) rubber liner and High Silica Phenolic liner.

Autoclave Moulding

A method of forming two surfaces of a panel utilising a two-sided mould set A stiff mould is located on the bottom, while a flexible membrane consisting of silicone or an extruded polymer film including nylon is located at the top. Reinforcement materials could be physically or robotically put. Recurrent fibre types made into textile structures are among them. They are frequently pre-impregnated with resin in the shape of prepreg textiles or unidirectional tapes. In certain cases, a resin film is applied to the lower mould, followed by dry reinforcement. The upper mould is placed, and the mould cavity is vacuumed. An autoclave is used to sterilise the arranged components. This procedure is usually carried out at both high and low pressure.This procedure is often carried out at both high pressure and high temperature. For optimal structural efficiency, usage of increased pressure allows for a high fibre volume fraction as well as minimal void content.

a method of forming both surfaces of a panel utilising a two-sided mould set The bottom is a rigid mould. The upper side might be either hard or flexible. Composite materials, silicone, and extruded polymer films like as nylon can all be used to create flexible moulds. The two halves are joined to create a mould chamber. The reinforcing materials are inserted into this cavity and the mould set is sealed before to the entrance of matrix material, which distinguishes resin transfer moulding. There are several types of resin transfer moulding, that vary in the mechanics of the way the resin is transferred to the reinforcement in the mould cavity. Vacuum infusion (for further details on resin infusion, view boat) is one of these different variants.Vacuum infusion and vacuum aided resin transfer moulding are two examples (VARTM).

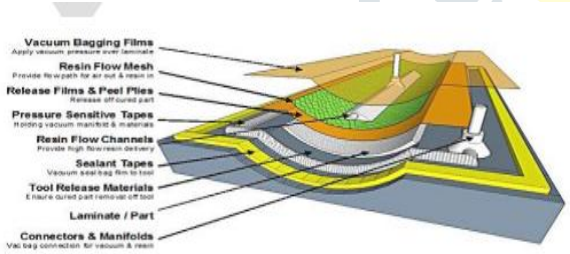

Fig 3: Resin Transfer Moulding

Maraging Steels

Maraging steels are steels (iron alloys) that have excellent durability and strength without compromising malleability, but are unable to maintain a good cutting edge. The term "ageing" relates to the prolonged heat-treatment proedure. These steels are a subset of low-carbon ultra-high-strength steels which get their strength as from precipitation of intermetallic compounds rather than carbon. Nickel accounts for 15 to 25% of the alloying element. Supplementary alloying elements such as cobalt, molybdenum, and titanium are used to create intermetallic precipitates. The initial research was conducted on 20 and 25% Ni steels with small additions of Al, Ti, and Nb.

Ethylene Propylene Diene Monomer (M-Class) Rubber (Epdm)

An elastomer is a form of synthetic rubber that has a diverse range of uses. The E stands for ethylene, the P stands for propylene, the D stands for diene, and the M stands for its categorization in ASTM standard D-1418. Rubbers with a polyethylene saturated chain are classified as "M." The diene(s) presently employed in the manufacturing of EPDM rubbers are DCPD (dicyclopentadiene), ENB (ethylidene norbornene), and VNB (vinyl norbornene).

Fig 4: EPDM foil

Their molecular structure has a significant impact on this. While cured with sulphur and resin, the dienes, which typically account for 2.5 wt% to 12 wt% of the composition, act as crosslinks. The diene (or third monomer) acts as a cogent in peroxide curing, providing resistance to unnecessary tackiness, creep, or flow throughout end use.

Non-Destructive Evaluation of High Silica Phenolic Liner

This section presented the examination of high silica phenolic liners using three non-destructive techniques for deformity assessment and detection radiography, infrared thermography, and ultrasonic testing.

Radiography

The term "radiography" refers to material investigation approaches that rely on the differential uptake of penetrating radiation, either electromagnetic radiation of very short wavelength or particulate radiation, even by portion or test specimens (object) getting examined. Different portions of a test section acquire various proportions of penetrating radiation due to variances in density and thickness of the section, or variances in absorption properties resulting from changes in composition. Such differences in penetrating radiation absorption can be inspected by identifying unabsorbed radiation which goes through the test section. Moreover, radiography can indeed relate to other radiological methods that could generate two-dimensional, plane-view visuals from unabsorbed radiation in a broad sense.

The Input voltage of the device used is 480V Nominal ±15% phase – to- phase or phase- to- neutral , the Frequency of the device is 60Hz, the Input power is 10kVA, the maximum Operating temperature is 0-90°C, the

Power factor is 0.8 typical, the Output power ranges from 5-450kV and the Output current ranges from 0.5 – 30mA.

Fig 5: High silica phenolic liner.

The testing was conducted at room temperature, using two observational techniques on a High Silica Phenolic liner, and according to the requirements listed below:

TECHNICAL PARAMETERS

MACHINE	METHOD	ENERGY (kV)	CURRENT(mA)	TIME (min)	FILM	SFD
Pantak(450kV)	Normal	75	2.7	2	T200	2m
Pantak(450kV)	Tangential	85	2.7	2	T200	2m

SFD: SOURCE TO FILM DISTANCE

Fig 6: Normal Radiography experimental setup

The radiograph shows no defects in the standard process. Because the defects are not parallel to the path of travel of the X-ray beam, they are not identified with this procedure. As a result, tangential radiography is used.

Tangential Radiography

The test was carried out on a Pantak 450kV X-ray machine. The liner is zone indicated with lines and placed perpendicular to the X-ray beam in this technique. The machine parameters have been established to X-ray. The voltage is 85kV, the current through the tube is 2.7mA, and the exposure time is 2 mins. To monitor the differential absorption of the radiation, the T200 (Kodak) X-ray film is positioned perpendicular to the tangent derived from the source to the film centre. The experiment is carried out individually at each tangent around the component. The film is analysed and observedin a film viewer that uses an automatic film processing device. At last, films are computerised using an AGFA Film Digitizer to preserve the data, and the outcomes are as follows.

Fig 7: Tangential Radiography experimental set up

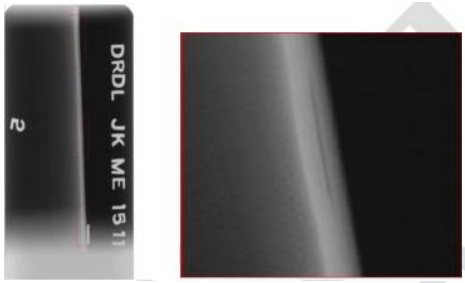

Fig 8: De-laminations are observed Tangential Radiograph of High Silica Phenolic liner

The radiograph certainly illustrates the de-laminations in the High Silica Phenolic liner as dark lines, as demonstrated by the arrow.

Film Processing

The invisible resulting image in the film by exposed to X-rays, Gamma rays, or light is made transparent and permanent during the processing process. The film is processed under restrained light of a colour where it is relatively insensitive. The film will be initially immersed in a developer solution, that darkens the radiation-exposed areas. The level of darkening for a provided stage of growth is determined by the amount of exposure. Upon progress, and occasionally following a treatment designed to suddenly stop the developer's reaction, the film is placed in a fixing bath. The fixer's job is to dissolve the darkened segments of the sensitive salt. The film is therefore cleaned and dried to delete the fixing chemicals and solubilized salts. There are two types of processing methods: manual processing and automated film processing.

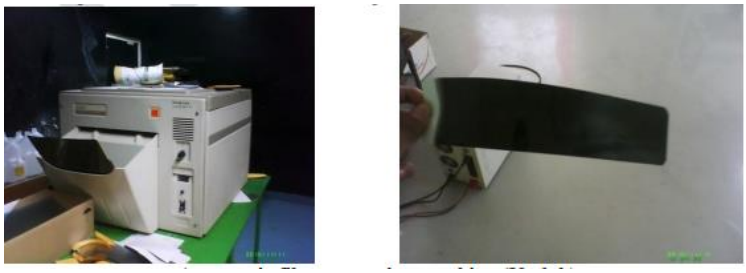

Fig 9: Automatic film processing machine (Kodak)

Fig 10: Manual film processing setup

Infrared Thermography

In recent times, there has been a significant increase in the use of Infrared Thermography as a non - destructive testing tool in industry and scientific applications. Much of this expansion can be attributed to advancements in infrared camera new tech, such as enhanced sensitivity, spatial resolution, and frame rates. Furthermore, advances in computer processing speeds have shortened the amount of time for temporal thermal image collection and analysis. Researchers are now capable of collecting larger amounts of data set both spatially and temporally, thereby increasing the size and thickness of specimens which can be evaluated by pulsed thermography.

At room temperature (20°C), the experiment was carried out. Depending on the position of the camera and the heat source, two techniques of inspection are feasible which are Transmission (heating from the other specimen section and Method of reflection (heat from the camera side)

Transmission Technique

The test was conducted using a transmission method in which the specimen was located on a table, the camera was correctly concentrated for a clear image, and it was positioned at a distance of 2 metres from the specimen. For 120 seconds, the specimen was evenly heated with a blower. A 1000W blower was applied to heat the specimen from within. The heating source is adjusted to assure heat distribution of the specimen. To identify defects, both the camera and the specimens's excitation (heating) began at the same time. from the experiment, the distances between the sample, IR camera, and heating source were kept constant. Thermal images were obtained at regular intervals of time during the heating and cooling stages of the specimen, as seen below.

Fig 11: High Silica Phenolic Through Transmission experimental set up

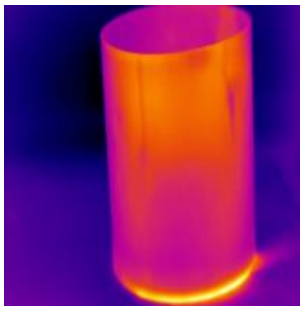

Fig 12: Thermal image of the High Silica Phenolic liner

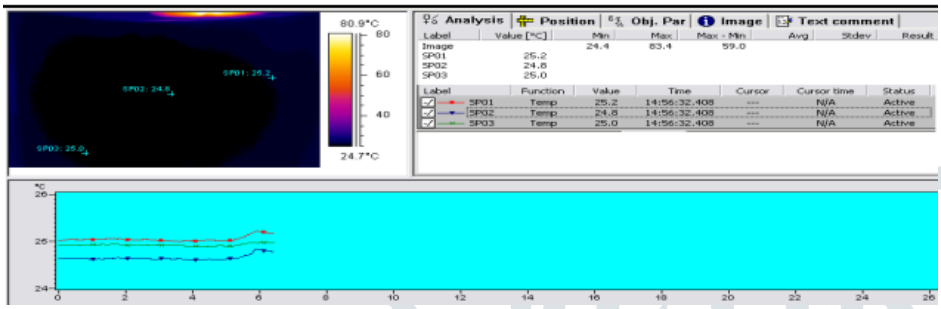

Fig 13: Thermal image after 6 seconds

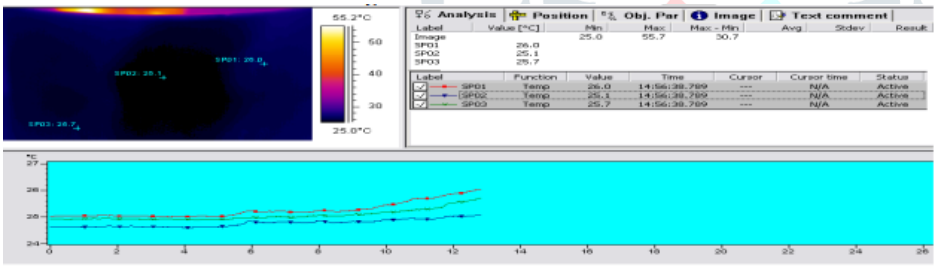

Fig 14: Thermal image after 12 seconds

The above thermograms simply illustrate that there is a temperature difference between the de-laminated (defect) region and the defect free area. Because the temperature in the defect region is lower (because of heat transfer characteristics) than in the defect free area, it is that the defect region has been recognised. The delaminated sections that occur within the first skin surface and the core exhibit the same thermal signature as the neighboring regions all through heating since they are burried deep within the heated surface. It is discovered that as the de-laminations move away from the heated surface, it takes longer for a thermal gradient to appear. While in heating process, thermal contrast was quite low in such delaminations. The existence of an airgap in between second skin face and the core material reduces thermal contrast while cooling. Such differences in thermal contrast can be seen in relation to time and temperature. It clearly shows temperature variation in the delaminated and defect-free areas.

The temperature increase and decay curve shows that now the delaminated area had a lower temperature than the defect-free region of the liner. The defect-free region takes 14 seconds to attain the temperature of 26.8°C, while

the delaminated area requires 20 seconds. As a result, the presence of delamination in the liner was analyzed quantitatively.

The temperature difference of the defect and non-defect areas is fully evident in the first derivative images. A logarithmic time-temperature graph can be used to explain this data.

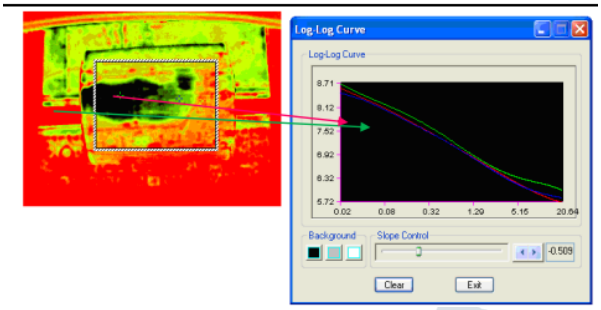

Fig 15: Log-Log curve for High Silica Phenolic liner

The red line denotes a non-defect. The green line represents defect-de-lamination at a shallow depth, while the blue line represents defect-de-lamination at a deeper depth.

Ultrasonic Testing (Through Transmission Method)

The transmission technique and the pulse-echo technique are the two main ultrasonic inspection techniques. The primary distinction between the two techniques is the fact that transmission technique only measures signal attenuation, whereas the pulse-echo procedure measures both transit time and signal attenuation.

The most popular ultrasonic technique, known as the pulse-echo method, includes listening for echoes that are created once an ultrasonic pulse is mirrored off of a trial piece's interface or discontinuity. This technique is employed to identify flaw location and thickness. The time-offlight seen between initial pulse and the echo generated by a flaw is used to calculate flaw depth. The relative transit time between the echo obtained by a flaw and the echo from the back surface may also be used to evaluate flaw depth. The amplitude of sound reflected from an interface (both within the sample material or at the back surface) is compared to the amplitude of sound reflected from a reference reflector of known size or from the back surface of a test section without flaws.

Ultrasonic testing has been used effectively in this study to identify defects in the composite liner. The test rig included a basic ultrasonic flaw detector and twin ultrasonic probes with a diameter of 10 mm and a working frequency of 500 KHz. Prior beginning the test , both probes (Transmitter and Receiver) must be measured since some energy may be lost due to rubber pads. Both would be managed to hold together and pressed to achieve 90% of the fullscreen by increasing gain. When positioning probes on the specimen, modify the gain till the signal covers 90% of the full screen. As a result, it is known as 47dB gain, and it achieves 90% of the fullscreen. At multiple grid points on the element, the magnitude of the obtained signal in terms of signal height was noted on the screen of the ultrasonic flaw detector.

Ultrasonic data of high silica phenolic liner instrument used is Masterscan310D, the method used is done through transmission, the probe applied is Dryscan500KHz, the number of Tested points is 72 and number of Defect points observed is 9.

Ultrasonic Report Of High Silica Phenolic Liner

Divide the acquired dB by the regard dB to determine material attenuation, i.e. at 50dB, 3dB (50-47= 3 dB) is the material attenuation at 500KHz frequency. It will attenuate more in specific areas than others. Because it is an anisotropic material (composite), attenuation does not occur uniformly throughout the component. De-lamination is presumed to be present if the variance in signal attenuation is higher than 6 dB as from reference dB and it is not attribute to anisotropic nature.

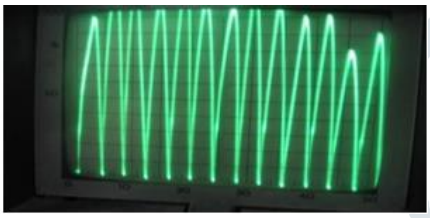

Fig 16: Non-Defect graph observed in CRT

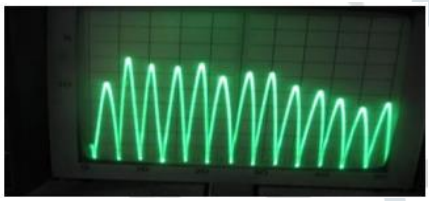

Fig 17: De-Lamination defect graph observed in CRT

The plot shows that there is a decrease in amplitude when particularly in comparison to the defect-free area because of obstruction generated by teflon inserts.

Part of the energy is transferred and a portion of it is reflected throughout multiple reflection examination. An air gap, a large mismatch in acoustic impedance, and the maximum amplitude of reflections from the debond point all contribute to debonding (bonding interface).

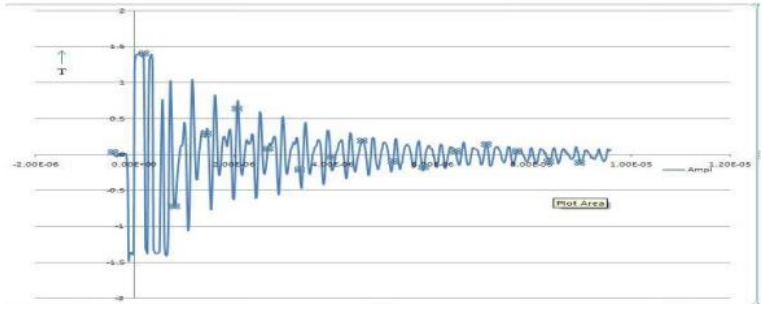

Fig 18: Debond side graph of the casing

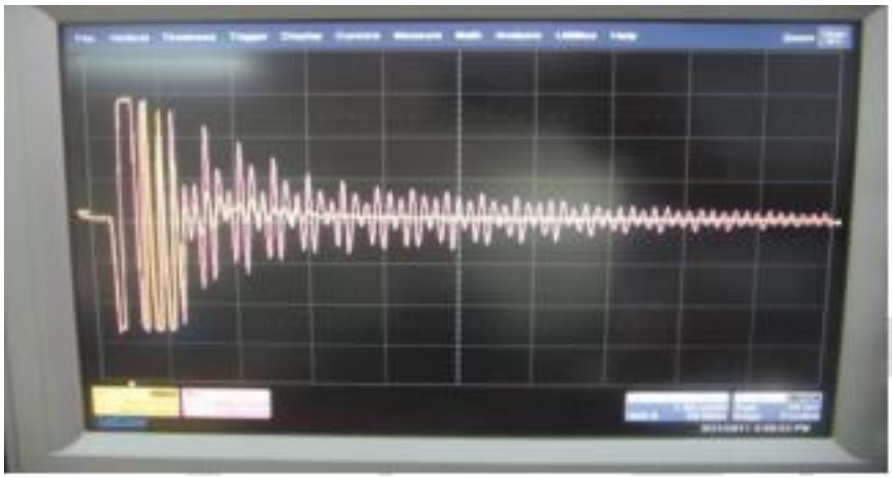

Fig 19: Oscilloscope image

The Fig clearly indicates that the yellow signal (output signal) is not attempting to follow the pink signal (reference signal), resulting in less signal (amplitude) than would be expected at a good bond point.

Conclusions

Contrast variations identified de-laminations and de-bonds in radiography. However, it is challenging to differentiate resin-rich, resin-starved regions from delaminations and debonds in radiography as the difference is not discernible, resolving the characteristics of defects is complicated, as well as another NDE technique may be required to maintain the data observed in radiography. Infrared Thermography specifically established de-laminations in the High Silica Phenolic Composite liner in addition to debonds in the Maraging steel liner. Thermography has been shown to be an outstanding method for identifying defects and assessing the extent of area mapping in a very quick amount of time. Defects were discovered during ultrasonic testing. However, determining the size of the defect using either pulse-echo testing or the dry coupling method is challenging. The relatively high dB in ultrasonic testing (Through Transmission), the more severe the delamination in radiography, and the greater the temperature in thermography (by double sided examination). Each NDE technique has benefits and limitations, but all NDE techniques are complementary.

References

[1].G.Boopathy, G.Surendar and Aun Nema, Review on Non-destructive testing of composite materials in aircraft applications, International Journal of Mechanical Engineering and Technology (IJMET) Volume 8, Issue 8, August 2017.

[2].Sanjay Kumar, Dalgobind Mahto, Recent trends in industrial and other engineering applications of Non-destructive testing, International Journal of Scientific & Engineering Research, Volume 4, Issue 9, September-2013.

[3].Francesco Ciampa, Pooya Mahmoodi, Fulvio Pinto and Michele Meo, Recent advances in active infrared thermograph for Non-destructive testing of aerospace components, Materials and Structures Centre (MAST), Department of Mechanical Engineering, University of Bath, 16 February 2018.

[4].Leonard J. Bond, Needs and opportunities: Non-destructive evaluation for energy systems, Center of Non-destructive Evaluation for Energy Systems, 2015.

[5].Razali N, Hameed Sultan M.T, and Jawaid M, A Review on detecting and characterizing damage Mechanisms of synthetic and natural Fibre based composites, Laboratory of Bio-composite technology, Institute of tropical forestry and forest products, University putra Malaysia, 2017.

[6].Philipp Johannes Tallafuss, Andrzej Rosochowski and Sylvia Campbell, A feasibility study on different NDT techniques used for testing bond quality in cold roll bonded Al-Sn alloy/steel bimetal strips, Manufacturing Rev, Volume 4, 2017.