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FABRICATION OF AEROSPACE COMPONENTS AND THEIR CHARACTERIZATION USING NON-DESTRUCTIVE EVALUATION METHODS

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ABSTRACT
Composite materials are one such class of materials which play a significant role in manufacturing of current and future aerospace components. Composite materials are particularly attractive to aerospace and military applications because of their exceptional strength & stiffness to density ratios, their chemical inertness and superior physical properties. Aerospace vehicles which operate at high temperature and high erosion environments need thermal protection to their internal subsystems and components. High Silica Phenolic ablative material is considered in the present study along with engineered ultra high strength steel material. One such kind is Maraging steel casing that is bonded inside with Ethylene Propylene Diene Monomer (EPDM) rubber liner as an ablative liner for thermal protection.
In the present work, two different types of artificial defects are created and studied viz.,
a) 'Delamination' between layers of High Silica Phenolic composite liner during fabrication and
b) 'Debond' between Maraging steel casing and rubber liner interface. Non-Destructive characterization both the above defects was performed using different NDE methods i.e., Radiography Testing, Infrared Thermography and Ultrasonic Testing. A comparative study is made between the results of different methods and techniques therein and the salient features are highlighted.
X-ray radiography is a non-contact and non-invasive in nature which revealed delamination/ debonds in the form of dark lines in the radiographs, Thermography revealed the defects in the form of contrast variation due to temperature difference and Ultrasonic testing is a contact that has shown acoustic impedance mismatches.

KEYWORDS: High Silica Phenolic, Ethylene Propylene Diene Monomer (EPDM), Maraging Steel, Radiography, infared Thermography, . Ultrasonic Testing.

INTRODUCTION
Composite materials usage is rapidly increasing in Aerospace and military applications. There are several manufacturing and processing trends emerging in the area of composites. To meet the challenges in manufacturing, processing and fabrication and to provide continuous feedback for improve the processes, modern methods and techniques are being explored and developed. Not only during the developmental phase but also during product realization stage, these advances in Non-Destructive Characterization and Evaluation methods and their support has become inevitable.
The range of applicable technologies and equipment varies with type of composite materials and structures. Testing is required to ensure that the composite structure has been built correctly. Appropriate testing that verifies that the component is effectively bonded and has the required strength, at the same time does not damage the part in any way. There are different NDE methods that can be used for testing.

FABRICATION OF HIGH SILICA PHENOLIC COMPOSITE LINER

The internal surface of the engine of the aerospace components is required to be protected from hot combustion gases of temperature about 2200°C. The ablative material selected for present case is High Silica Phenolic.

EQUIPMENT REQUIRED

- Prepreg Machine
- Filament winding Machine
- Autoclave
- Lathe with FRP Dust Extraction System

FABRICATION METHODOLOGY

Cylindrical liner is fabricated by hand lay-up and Autoclave cured technique. Following steps are involved in fabrication.

- Mandrel preparation
- Prepreg Lay up
- Curing of Lay up
- Machining of cured component
- Extraction of Machined component

MANDREL PREPARATION

1) Mandrel is loaded on filament winding machine.
2) Mandrel surface is smoothened with emery paper.
3) Mandrel is cleaned and de-greased with acetone and wax polish.
4) Two coats of high Temperature release Agent is applied all-over cleaned and de-greased surface of the mandrel for easy extraction of cured component.

High silica fabric and Phenolic resin specifications are given below in table.

HIGH SILICA SPECIFICATIONS

S.NO	PARAMETER	NOMINAL VALUE
1	Break Strength Warp(min) Kg/mm Weft(min)	0.711 0.428
2	Thread count Wrap End/25mm Weft	48-56 36-44
3	Weave	8 H satin
4	Thickness mm	0.74-0.94
5	Width mm	1000
6	Arial density kg/sqm	0.578-0.679
7	PH min	3.0
8	Arial Shrinkage Maximum %	5
9	Silica Content Minimum %	98
10	Specific gravity	1.9-2.1

SPECIFICATIONS OF PHENOLIC RESIN

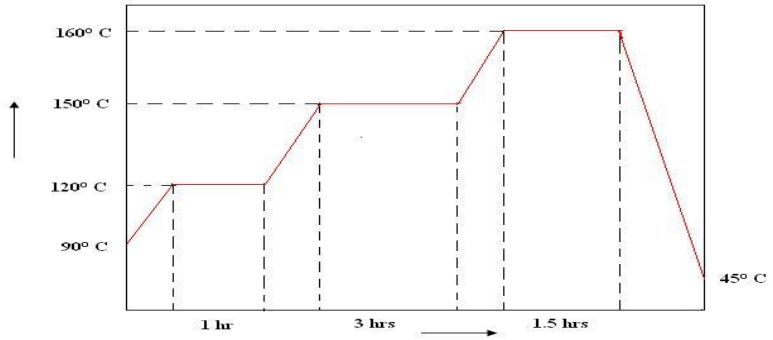
S.NO	Parameter	Nominal (at the time of procurement)	Nominal (at the time of prepregging)
1	Specific Gravity	1.12-1.16	1.12-1.16
2	Viscosity at 30°C	150-350	150-600
3	Point of Trouble, cc	6.0-12.0	6.0-7.0
4	Volatile Content	32-38%	32-38%
5	Solid content	60-65%	60-65%

PREPREG LAYUP AND TEFLON INSERTS (DEFECT)

Five layers of High Silica Phenolic prepreg are laid up over the aluminum alloy mandrel. Two circumferential joints are given in each layer. These joints in all 5 layers (10 pieces of prepreg) are staggered on the circumference of the mandrel in order to avoid weak zones in the final component. 10mm overlap is given in all 10 prepreg pieces. For calculation of prepreg dimension, mandrel diameter is taken as 273mm. Width of the prepreg is calculated as ((3.1415D/2) +10) mm. Mandrel is kept in slow rotation to facilitate the lay up operation and Teflon insert is done in between the layers in order to create artificial de-lamination. After lay up of prepreg layers on the mandrel, 2 layers of hoop winding are given at a high tension for the consolidation of the component. 5mm thickness is built up (extra thickness is given for machining allowance) by layup and hoop winding.

CURING OF THE LAYED UP COMPONENT

Layed up component along with mandrel is kept in vacuum bag. The bag is tailored to the component size so that wrinkles are minimized. Release fabric is wrapped on lay up; over this three layers of breather material are wrapped. This breather wrapped component is kept in vacuum bag. Vacuum port is provided through which air and volatile products inside vacuum bag are sucked out. Curing is carried out in autoclave under pressure 4 bar, temperature 150-160°C maximum and vacuum 0.9.



Curing cycle of High Silica Phenolic

MACHINING OF CURED LINERS

Cured component in vacuum bag is taken out of autoclave after curing. De-bagging is done. Barcol hardness is measured for curing check. It will be in the range of 60-70 mandrel along with cured component is loaded on lathe to carry out machining. Hoop winding layers are machined out first. Then outer diameter of liners is turned in minimum two turnings, one rough turning and one final turning (finish turning is carried out at high speed). Outer diameter is measured while component is on the mandrel. Parting is done after outer diameter is achieved.

MARAGING STEEL LINERS BONDED INSIDE WITH EPDM RUBBER BONDING DETAILS

The abrasion process is used for obtaining the rough surface finish on the inner surface of the Maraging steel, epoxy resin is applied to the inner surface. EPDM rubber liner is bonded inside to the metal casing by epoxy resin and allowed to bond firmly. The de-bonding areas are artificially created for the study with the external source.

EPDM rubber bonded inside to Maraging steel casing

After machining and bonding, the two components are tested for detecting de-lamination and de-bond using three different NDE methods such as Radiography, Infrared Thermography and Ultrasonic Testing.

OBJECTIVE

The objective of the thesis mainly focuses on using three NDE methods for characterization of de-bonds & de-laminations

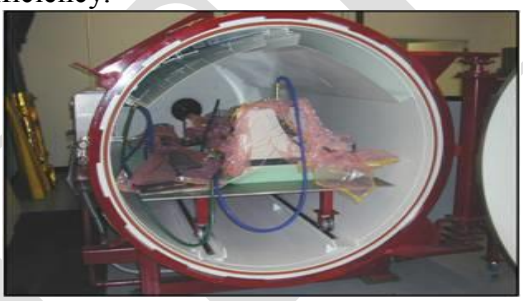
- Radiography
- Infrared Thermography
- Ultrasonic testing

On the following two components

- High Silica Phenolic liner
- Maraging steel casing with Ethylene Propylene Diene Monomer (EPDM) rubber liner. .

AUTOCLAVE MOULDING

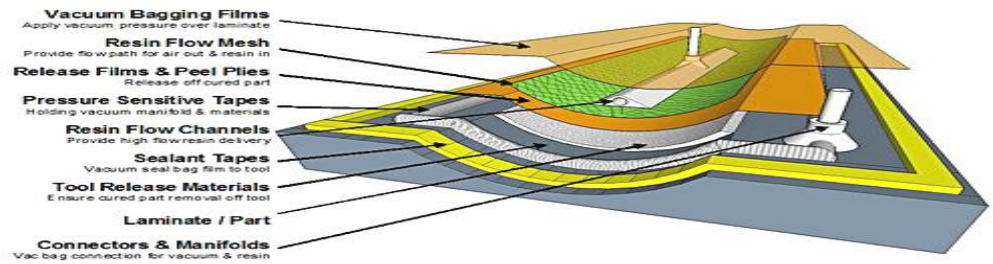
A process using a two-sided mould set that forms both surfaces of the panel. On the lower side is a rigid mould and on the upper side is a flexible membrane made from silicone or an extruded polymer film such as nylon. Reinforcement materials can be placed manually or robotically. They include continuous fibre forms fashioned into textile constructions. Most often, they are pre-impregnated with the resin in the form of prepreg fabrics or unidirectional tapes. In some instances, a resin film is placed upon the lower mould and dry reinforcement is placed above. The upper mould is installed and vacuum is applied to the mould cavity. The assembly is placed into an autoclave. This process is generally performed at both elevated pressure and elevated temperature. The use of elevated pressure facilitates a high fibre volume fraction and low void content for maximum structural efficiency.



Autoclave Moulding

RESIN TRANSFER MOULDING (RTM)

A process using a two-sided mould set that forms both surfaces of the panel. The lower side is a rigid mould. The upper side can be a rigid or flexible mould. Flexible moulds can be made from composite materials, silicone or extruded polymer films such as nylon. The two sides fit together to produce a mould cavity. The distinguishing feature of resin transfer moulding is that the reinforcement materials are placed into this cavity and the mould set is closed prior to the introduction of matrix material. Resin transfer moulding includes numerous varieties which differ in the mechanics of how the resin is introduced to the reinforcement in the mould cavity. These variations include everything from vacuum infusion (for resin infusion see also boat building) to vacuum assisted resin transfer moulding (VARTM).



Resin Transfer Moulding

ADVANTAGES OF COMPOSITES

Summary of the advantages exhibited by composite materials, which are of significant use in aerospace industry are as follows:

- High resistance to fatigue and corrosion degradation.
- High 'strength or stiffness to weight' ratio. As enumerated above, weight savings are significant ranging from 25-45% of the weight of conventional metallic designs.
- Due to greater reliability, there are fewer inspections and structural repairs.
- Directional tailoring capabilities to meet the design requirements. The fibre pattern can be laid in a manner that will tailor the structure to efficiently sustain the applied loads.

MARAGING STEELS

Maraging steels are steels (iron alloys) which are known for possessing superior strength and toughness without losing malleability, although they cannot hold a good cutting edge. Aging refers to the extended heat-treatment process. These steels are a special class of low-carbon ultra-high-strength steels which derive their strength not from carbon, but from precipitation of inter-metallic compounds. The principal alloying element is 15 to 25% nickel. Secondary alloying elements are added to produce intermetallic precipitates, which include Cobalt, Molybdenum, and Titanium. Original development was carried out on 20 and 25% Ni steels to which small additions of Al, Ti, and Nb were made.

ETHYLENE PROPYLENE DIENE MONOMER (M-CLASS) RUBBER (EPDM)

A type of synthetic rubber is an elastomer which is characterized by a wide range of applications. The E refers to Ethylene, P to Propylene, D to diene and M refers to its classification in ASTM standard D-1418. The "M" class includes rubbers having a saturated chain of the polyethylene type. The diene(s) currently used in the manufacture of EPDM rubbers are DCPD (dicyclopentadiene), ENB (ethylidene norbornene) and VNB (vinyl norbornene).

EPDM foil

This is very much influenced by their molecular structure. The dienes, typically comprising between 2.5 wt% up to 12 wt% of the composition serve as crosslink's when curing with sulphur and resin, with peroxide cures the diene (or third monomer) functions as a cogent, which provide resistance to unwanted tackiness, creep or flow during end use.

MECHANICAL PROPERTIES

Hardness, Shore A : 40 – 90
Tensile Failure Stress, Ultimate : 25 MPa
Density : Can be compounded from 0.90 to >2.00 gcm^{-3}

THERMAL PROPERTIES

CTE, linear 68°F : 875µm m^{-1} $°C^{-}$
Maximum Service Temperature, Air : 100-120 °C
Minimum Service Temperature, Air : -54 °C
Glass Temperature : -54 °C

NON-DESTRUCTIVE EVALUATION OF HIGH SILICA PHENOLIC LINER

INTRODUCTION

This chapter discusses about the inspection of High Silica Phenolic liner with three Non Destructive Methods namely Radiography, Infrared Thermography and Ultrasonic Testing for detection and evaluation of defects.

RADIOGRAPHY

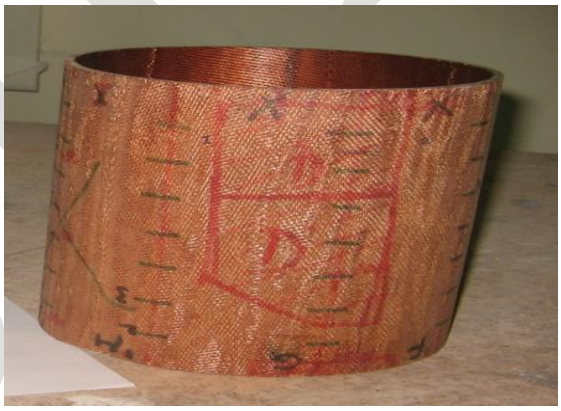
RADIOGRAPHY is the general term given to material inspection methods that are based on the differential absorption of penetrating radiation, either electromagnetic radiation of very short wavelength or particulate radiation by the part or test piece (object) being inspected. Because of differences in density and variations in thickness of the part or differences in absorption characteristics caused by variations in composition, different portions of a test piece absorb different amounts of penetrating radiation. These variations in the absorption of the penetrating radiation can be monitored by detecting the unabsorbed radiation that passes through the test piece. In a broad sense, however, radiography can also refer to other radiological techniques that can produce two-dimensional, plane-view images from the unabsorbed radiation.

EQUIPMENT SPECIFICATIONS

The equipment used for the present experiments is Pantak 450kV X-ray machine

Input voltage	: 480V Nominal ±15% phase – to- phase or phase- to- neutral
Frequency	: 60Hz
Input power	: 10kVA, maximum
Operating temperature	: 0-90°C
Power factor	: 0.8 typical
Output power	: 5-450kV
Output current	: 0.5 – 30mA

Experimental Details



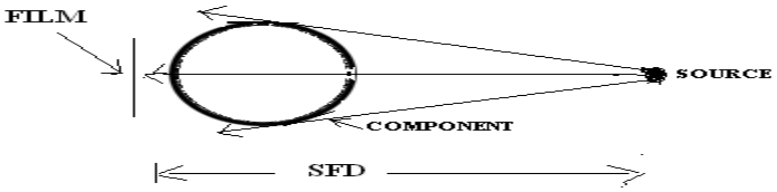
High Silica Phenolic liner

The experiment was performed at room temperature, two methods of observations are done on High Silica Phenolic liner and the experiments are carried out as per specifications mentioned 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



Normal Radiography schematic Block diagram

Normal Radiography experimental setup

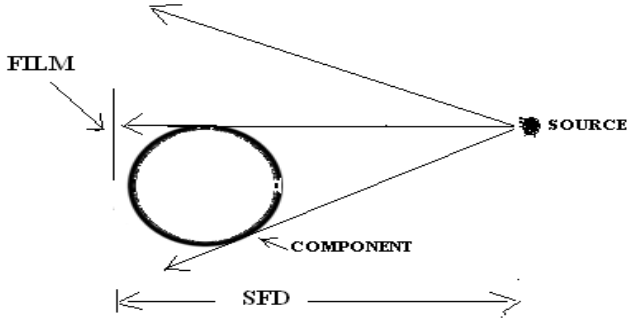
RESULTS AND DISCUSSIONS

Normal Radiograph of High Silica Phenolic liner

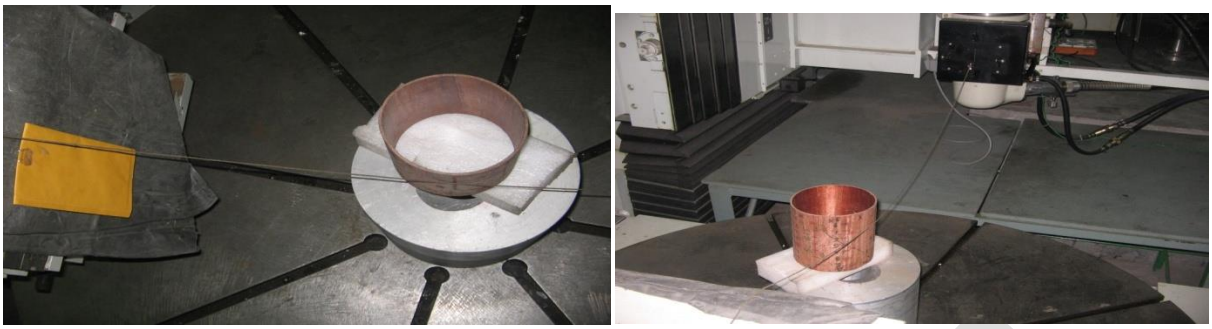
From the Radiograph, no defects are observed in normal method. As the defects are not in parallel to the direction of X-ray beam travel and therefore not detected by this method. Hence Tangential Radiography is conducted.

TANGENTIAL RADIOGRAPHY

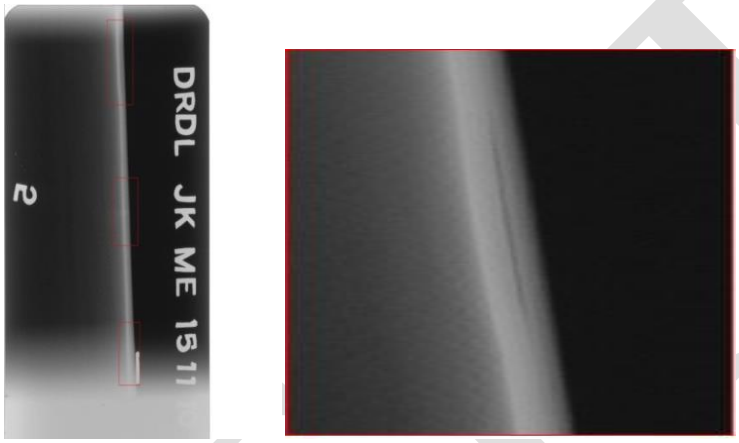
The experiment was conducted on Pantak 450kV X-ray machine. In this method the liner is zone marked with lines and positioned perpendicular to the X-ray beam. The machine parameters are set to be X-ray Energy: 85kV, Tube current: 2.7mA and exposure time: 2 mins. A T200 (Kodak) X-ray film is placed perpendicular to the tangent drawn from source to the film center to record the differential absorption of the radiation. The experiment is conducted individually at each and every tangent at all around the component. The film is processed using an automatic film processing machine and viewed under film viewer. Finally, films are digitized employing an AGFA Film Digitizer for preserving the data and the following results are observed.



Tangential Radiography schematic Block diagram



Tangential Radiography experimental set up

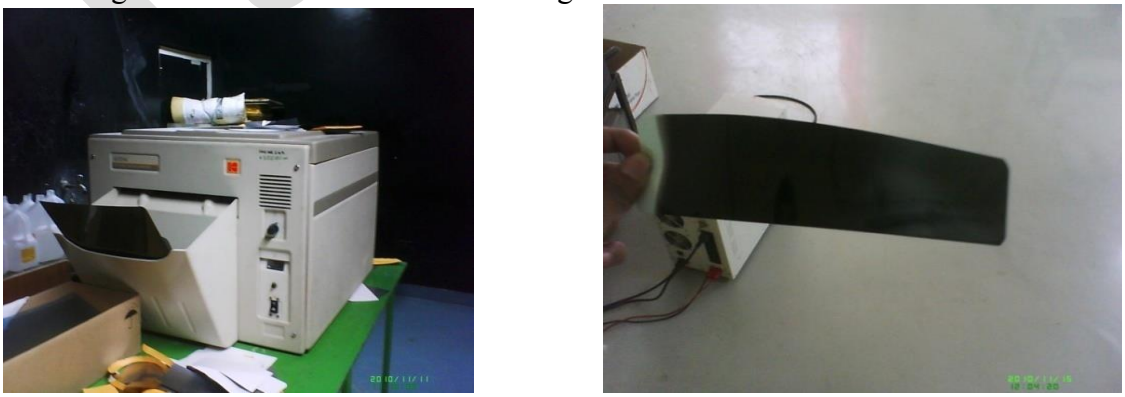


De-laminations are observed
Tangential Radiograph of High Silica Phenolic liner

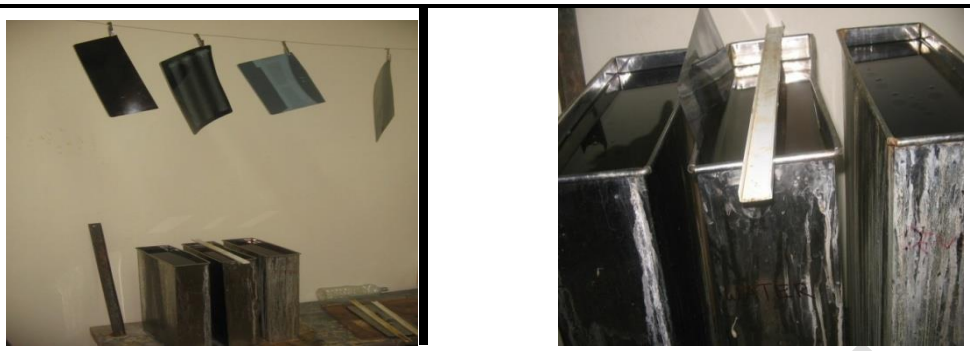
The Radiograph clearly reveals the de-laminations in High Silica Phenolic liner in the form of dark lines as indicated with arrow.

Film Processing

In the processing procedure, the invisible image produced in the film by exposure to X-rays, Gamma rays or light is made visible and permanent. Processing is carried out under subdued light of a color to which the film is relatively insensitive. The film is first immersed in a developer solution, which causes the areas exposed to radiation to become dark, the amount of darkening for a given degree of development depending on the degree of exposure. After development, and sometimes after a treatment designed to halt the developer reaction abruptly, the film passes into a fixing bath. The function of the fixer is to dissolve the darkened portions of the sensitive salt. The film is then washed to remove the fixing chemicals and solubilized salts, and finally is dried. Processing techniques can be divided into two general classes: "Manual Processing" and "Automated Film Processing".



Automatic film processing machine (Kodak)



Manual film processing setup

INFRARED THERMOGRAPHY

The use of Infrared Thermography as a nondestructive testing tool in industrial and research applications has seen considerable growth in recent years. Much of this growth is due to infrared camera technology improvements with increased sensitivity, spatial resolution and frame rates. In addition, the advancement of computer processing speeds has reduced the time required for acquisition and analysis of the temporal thermal images. With this increase in computational capability, researchers are able to capture larger data sets, both spatially and temporally, thus increasing the size and thickness of the samples that can be analyzed by pulsed Thermography.

EQUIPMENT DETAILS

The Thermal imaging for all the samples was carried out by using ThermaCAM SC3000 manufactured by FLIR systems. The system consists of a rugged IR camera with a built-in 20° lens, Quantum Well Infrared Photon Detector (QWIP) with sterling cooling (up to -203.15°C, cooling down time <6min) cycle, cables and connectors. The spectral response of the IR camera is 8-9µm. The thermal resolution of the camera is 0.03° at 30°C. The lens that was used in this experiment has at 2M object distance 0.3, 6M field of view (FOV); Accuracy is ±2% or ±2°C. The image storage is 14 bit digital image and covers range of temperatures varying from-20°C to 2000°C. The Thermograms are analyzed using ThermaCAM Researcher Professional software.

ThermaCAM SC3000

EXPERIMENTAL DETAILS

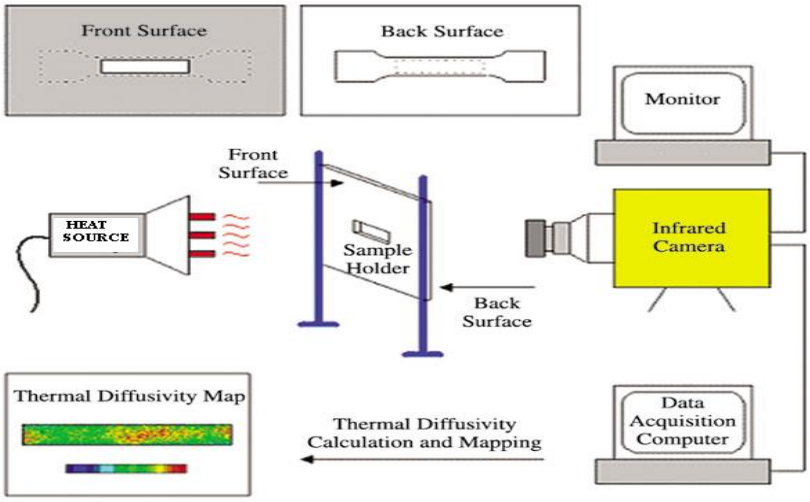
The experiment was performed at room temperature (20°C). Two methods of observations are possible based on the location of the camera and the heat source:

- Transmission (heating from the other side of the specimen)
- Reflection technique (heating from the camera side)

TRANSMISSION TECHNIQUE

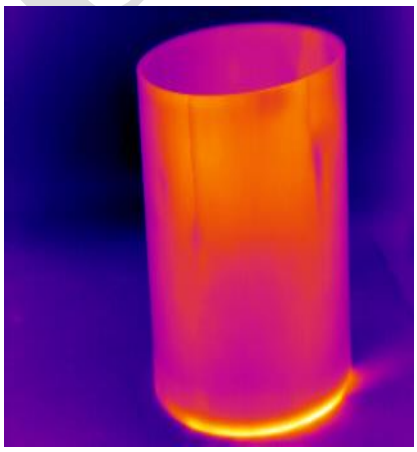
The experiment was carried out by through transmission technique in which the sample is positioned on the table, the camera is focused properly for clear image and placed at a distance of 2 meters from the sample. The sample was heated uniformly using blower for a period of 120 seconds. A blower of 1000W was used to heat the sample from inside. The heating source is manipulated in such a way to ensure uniform heating of the specimen. Both camera and excitation (heating) of the sample started at the same time to detect the defects. The distances among the sample, IR camera and heating source were kept constant throughout the

experiment. Thermal images were captured during heating and cooling phases of the specimen at regular intervals of time as shown below.



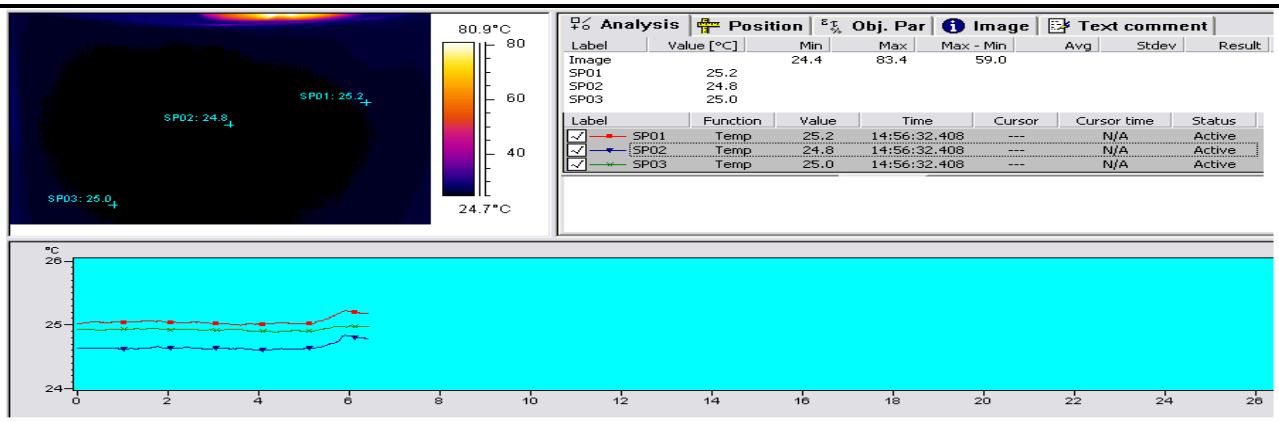
Schematic Block diagram of Through Transmission test

High Silica Phenolic Through Transmission experimental set up

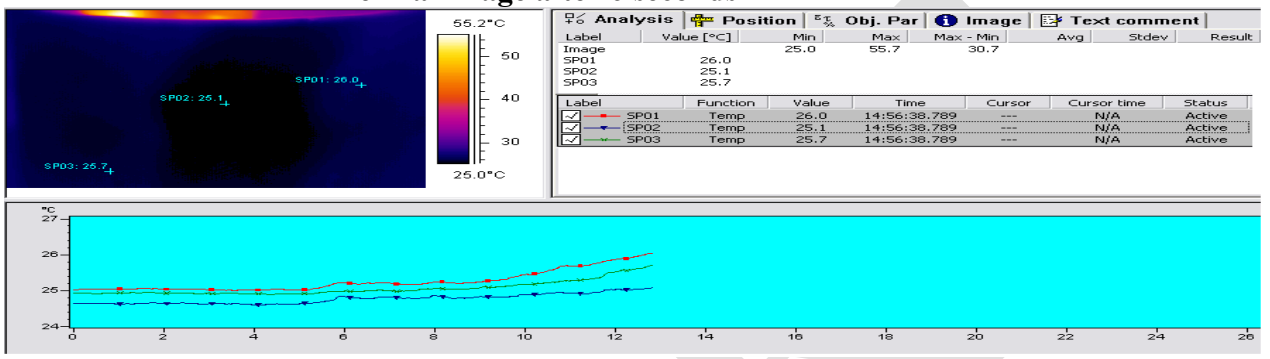


Thermal image of the High Silica Phenolic liner

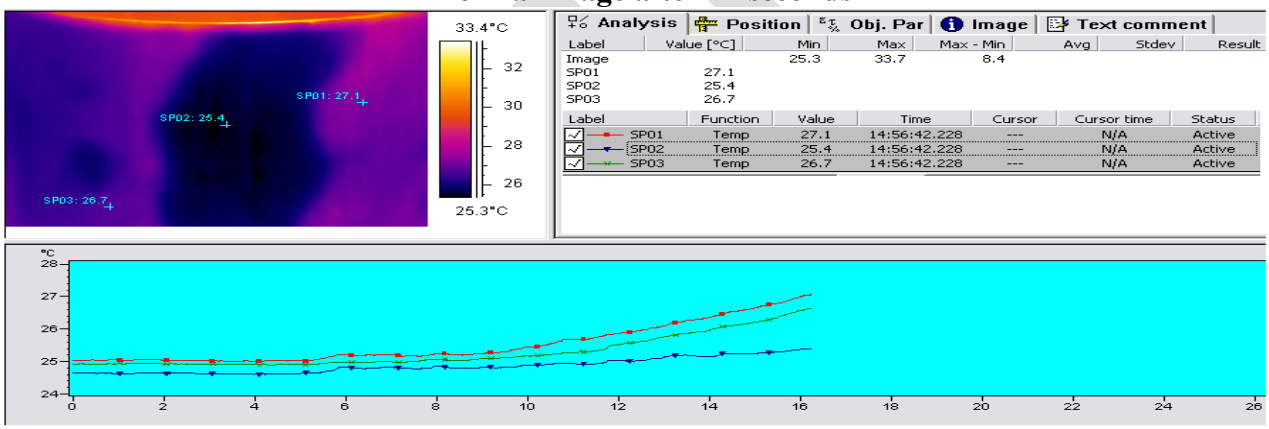
RESULTS AND DISCUSSION



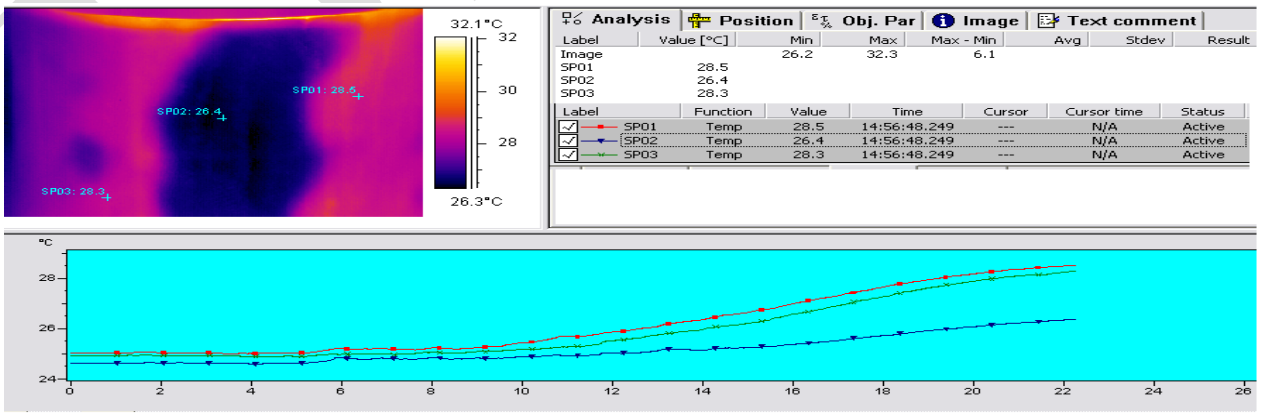
Thermal image after 6 seconds



Thermal image after 12 seconds



Thermal image after 15 seconds



Thermal image after 20 seconds

Thermograms of High Silica Phenolic liner at various time intervals

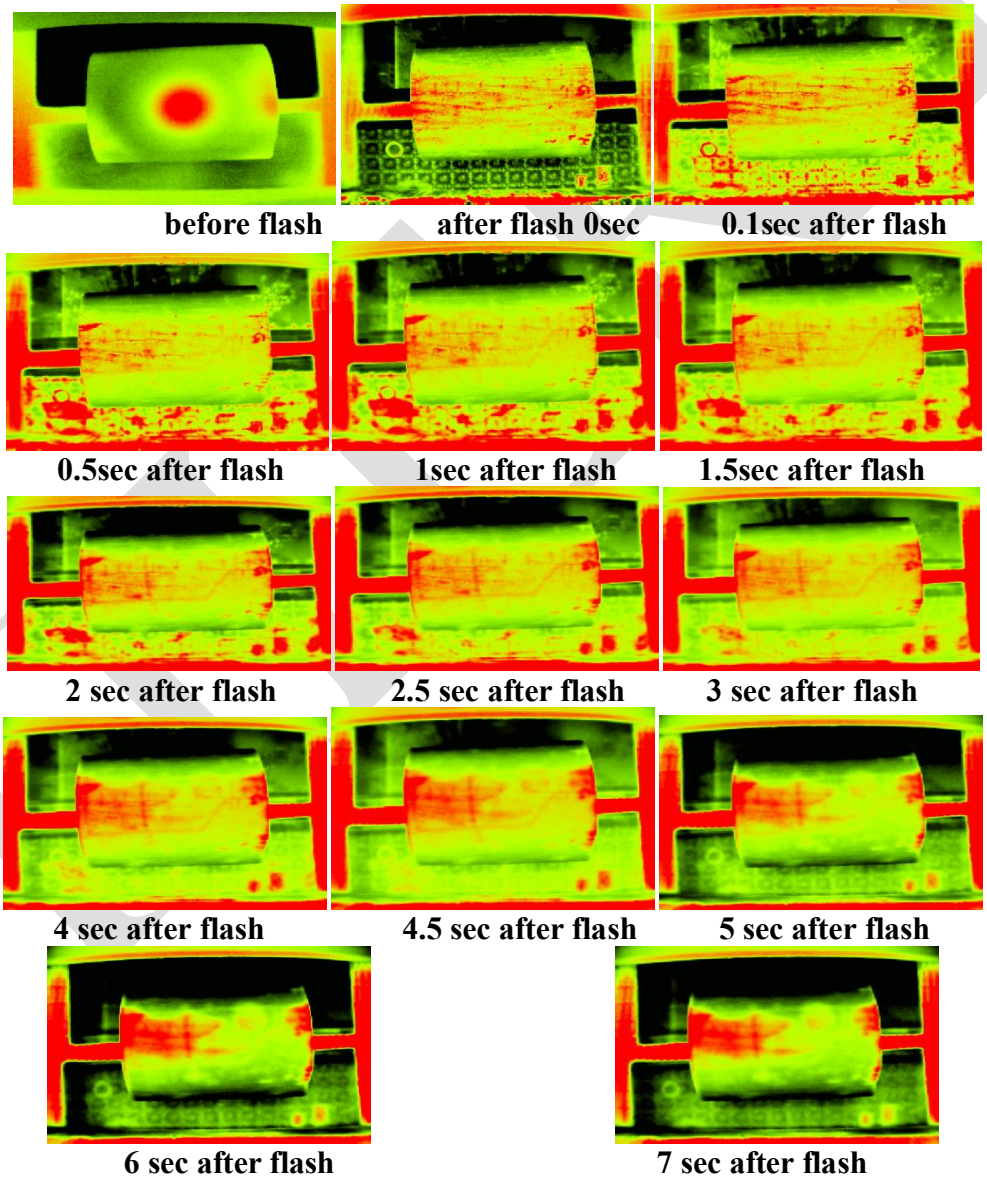
From the above thermograms, it is clearly observed that there is a temperature variation from De-laminated (Defect) region to that of defect free region. As the temperature is less in defect region (due to Heat Transfer

properties) compared to defect free region, so from these thermograms can say that the area of defect is identified, it is observed that during heating of the specimen, the delaminated portions that exists in between the first skin surface and the core shows the same thermal signature as that of surrounding regions as they are burried deep inside the heated surface. It is observed that, as the de-laminations are far from the heated surface, takes more time to show thermal gradient. In these delaminations thermal contrast was very less during the heating process. While cooling, the thermal contrast is less due to the presence of airgap between the second skin face and the core material. These thermal contrast variations can be observed with respect to time and temperature. It shows clear indication of temperature variation of the delaminated and defect free regions.

From the temperature rise and decay curve, it can be observerd that the delaminated region had low temperature compared to the defect free region of the liner. In order to reach the temperature of 26.8°C, the defect-free region takes less time i.e, 14 seconds and the delaminated region takes 20 seconds. Hence, the existance of the delamination in the liner was clearly detected.

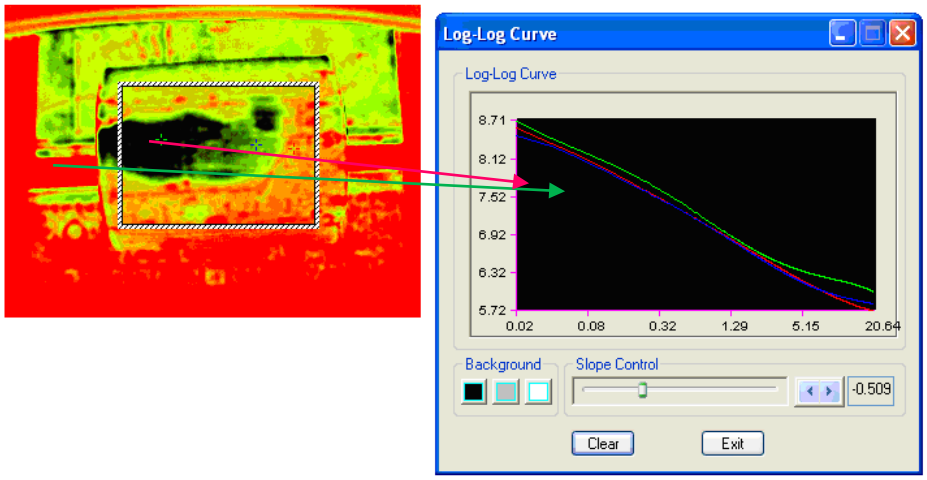
RESULTS AND DISCUSSIONS

FIRST DERIVATIVE



Derivative images of the composite liner using reconstructed thermal image data

The first derivative images clearly reveals the temperature variations of the defect and non defect regions, this interpretation can be done logarithmic time-temperature plot.



Log-Log curve for High Silica Phenolic liner

- Red line indicates non-defect
- Green line indicates defect-de-lamination shallow depth
- Blue line indicates defect-de-lamination deeper depth

ULTRASONIC TESTING (THROUGH TRANSMISSION METHOD)

The two major methods of ultrasonic inspection are the transmission method and the pulse-echo method. The primary difference between these two methods is that the Transmission method involves only the measurement of signal attenuation, while the pulse-echo method can be used to measure both transit time and signal attenuation.

The pulse-echo method, which is the most widely used ultrasonic method, involves the detection of echoes produced when an ultrasonic pulse is reflected from a discontinuity or an interface of a test piece. This method is used in flaw location and thickness measurements. Flaw depth is determined from the time-of-flight between the initial pulse and the echo produced by a flaw. Flaw depth might also be determined by the relative transit time between the echo produced by a flaw and the echo from the back surface. Flaw sizes are estimated by comparing the signal amplitudes of reflected sound from an interface (either within the test piece or at the back surface) with the amplitude of sound reflected from a reference reflector of known size or from the back surface of a test piece having no flaws.

EQUIPMENT SPECIFICATIONS

a) Masterscan 310D

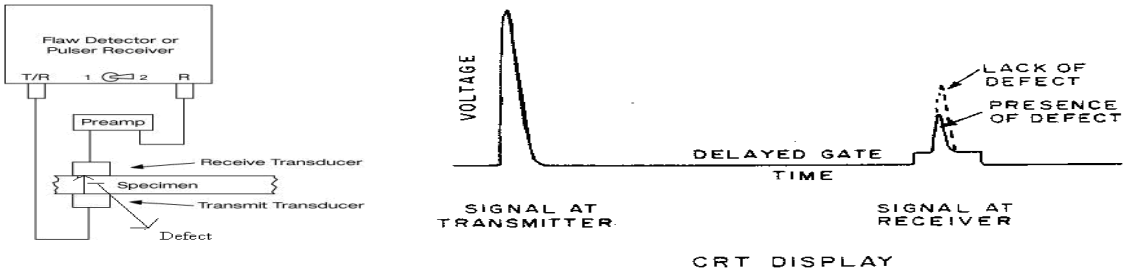
Pulse repetition frequency (PRF)	:	500 KHz
Auto-PRF Accuracy Cumulative to within	:	±0.7dB
Test range	:	10mm to 5m.
Delay (pulse shift)	:	0 to 1000mm, ±1%
Velocity	:	1200m/s to 7200m/s
Gain control	:	99 dB in 10 dB and 1 dB
Delay(pulse shift)	:	0 to 1000mm, ±1%
Time base linearity	:	±1%full screen width
Temperature	:	Working: 20 to 55ºC
Storage	:	-20 to 70ºC
Output display	:	Lecroy 64 Xi

b) LeCroy 64Xi oscilloscope

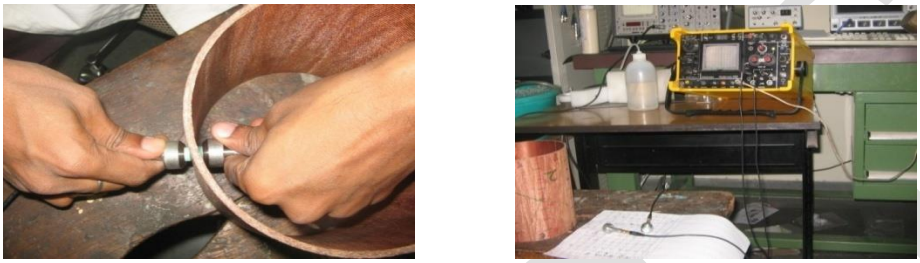
Voltage	100–240 VAC ±10% at 50/60 Hz; 115Vrms ±10% at 380- ;
420Hz Automatic AC Voltage Selection;	
Offset Accuracy	± (1.5% of offset value +0.5% of full scale +1mV)
Power Consumption	340 VA / 340 W (290 VA / 290 W for 62Xi-A)
Temperature (Operating)	+5 °C to +40 °C

Resolution	SVGA; 800 x 600 pixels. Maximum external monitor output
resolution of 2048 x 1536 pixels.	

EXPERIMENTAL DETAILS



The Through Transmission test configuration and a schematic of CRT Display



Through Transmission test experimental set up

Ultrasonic testing was successfully used in the present study to determine the defects in composite liner. The experimental set-up consisted of standard ultrasonic flaw detector and twin ultrasonic probes of diameter 10mm, the working frequency of which was 500 KHz. Before conducting the experiment, both (Transmiiter and Reciever) probes need to calibrate as because of rubber pads, some of the energy might be lossing. Both are held together and applied with some pressure to attain 90% of the fullscreen by increasing gain. Whenever positioning probes on the sample, need to adjust the gain untill to attain the signal for 90% of the fullscreen. Hence it is callibirated for 47dB gain, attaining for 90% of the fullscreen. The magnitude of the received signal in terms of signal height on the screen of the ultrasonic flaw detector was recorded at various grid points on the component.

RESULTS AND DISCCUSSIONS

ULTRASONIC REPORT OF HIGH SILICA PHENOLIC LINER
INSTRUMENT : Masterscan310D
METHOD : Through transmission
PROBE : Dryscan500KHz
Number of Tested points:72
Number of Defect points observed: 9

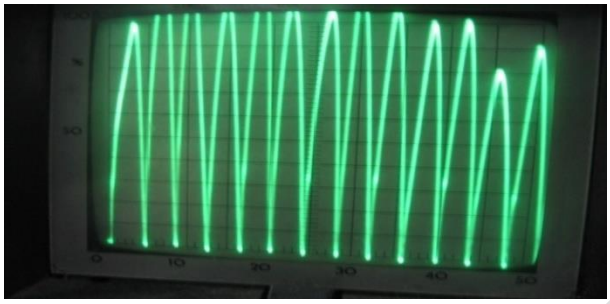
ULTRASONIC REPORT OF HIGH SILICA PHENOLIC LINER

Attenuation values in dB Reference: 47dB

S.No	A	B	C	D	E	F	G	H
1	49	49	50	52	52	49	50	50
2	50	49	50	50	56	50	53	50
3	53	49	50	50	50	49	50	50
4	53	49	50	50	50	49	70	50
5	50	49	50	50	50	49	73	50
6	50	49	50	49	50	50	77	68
7	50	49	50	50	50	50	77	74
8	50	49	50	50	50	52	72	58
9	48	49	50	50	50	53	70	50

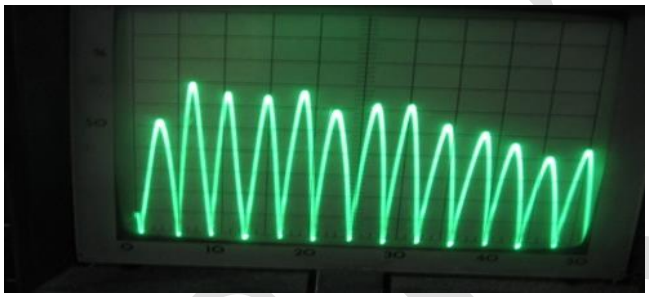
To get material attenuation**,** Obtained dB – Reference dB i.e at 50dB, 3dB(50-47= 3 dB) is the material attenuation at 500KHz frequency. Some regions it will more attenuate and some may less attenuate, since it

is an anisotropic material(composite) attenuation is not uniform all over the component. If the variation in signal attenuation is more than 6 dB to the reference dB, is not due to anisotropic nature, then it is considered to be existance of de-lamination.



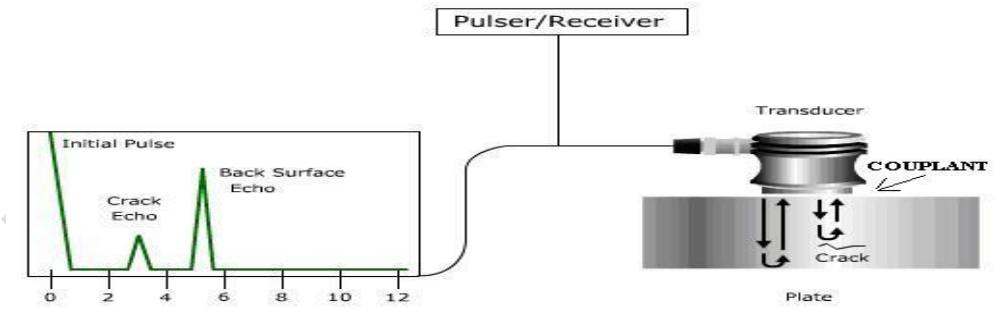
Non-Defect graph observed in CRT

By the attenuation method can say that the at the defect free region there is high strength in amplitude is observered.

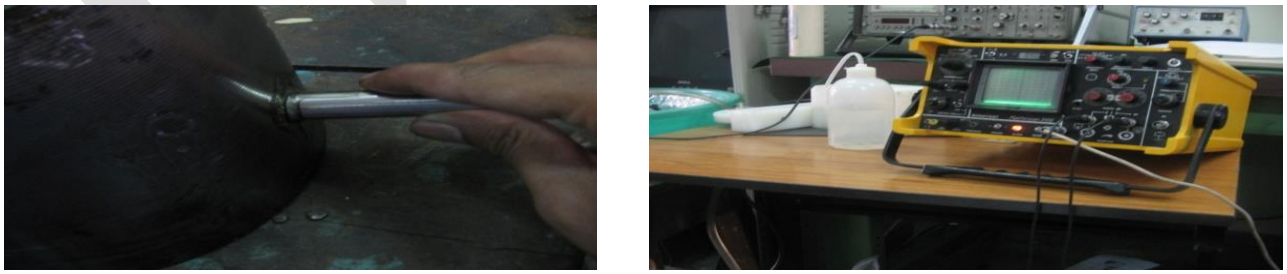


De-Lamination defect graph observed in CRT

From the graph, it is observed that there is a fall in amplitude compared with defect free region due to obstruction caused by teflon inserts.



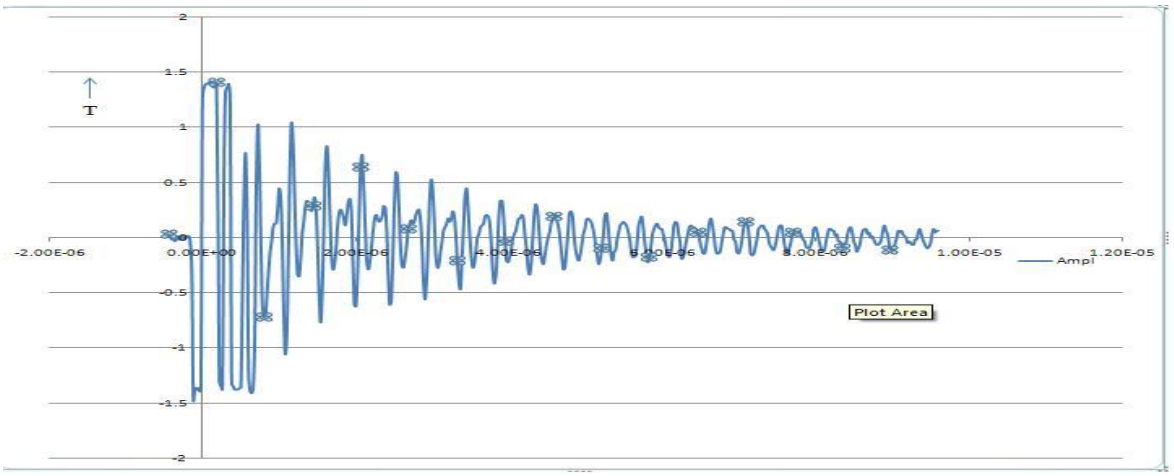
Pulse-Echo test schematic Block diagram



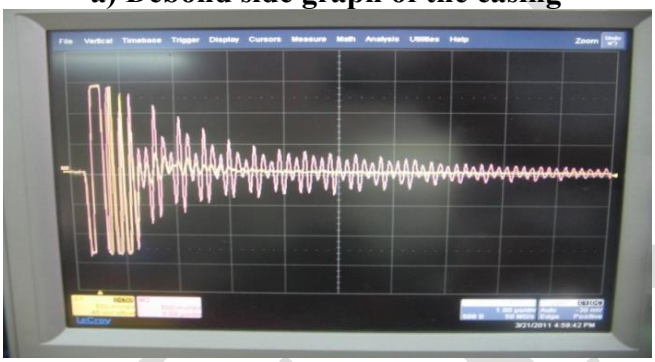
Pulse-Echo test experimental set up

RESULTS AND DISCUSSIONS

During inspection by multiple reflection method, part of energy is transmitted and part of energy is reflected. Debond due to air gap, large mismatch of acoustic impedance, maximum amplitude of reflections are coming from debond point (bonding interface).

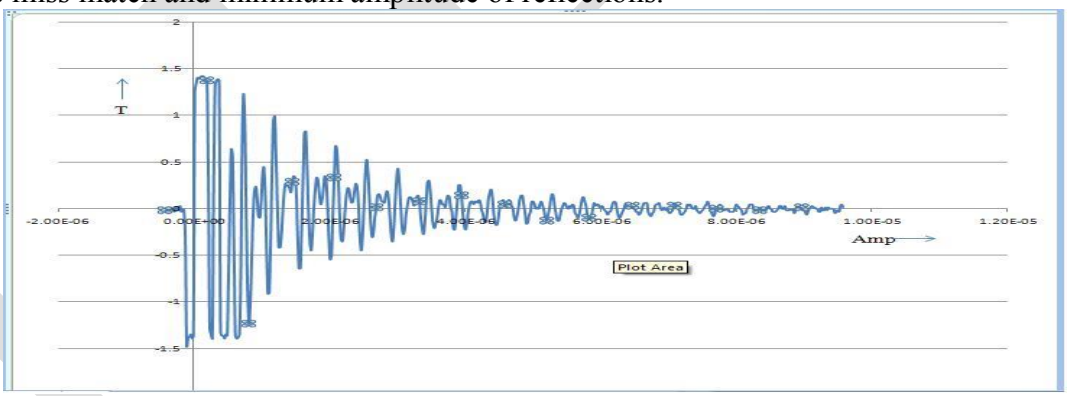


a) Debond side graph of the casing

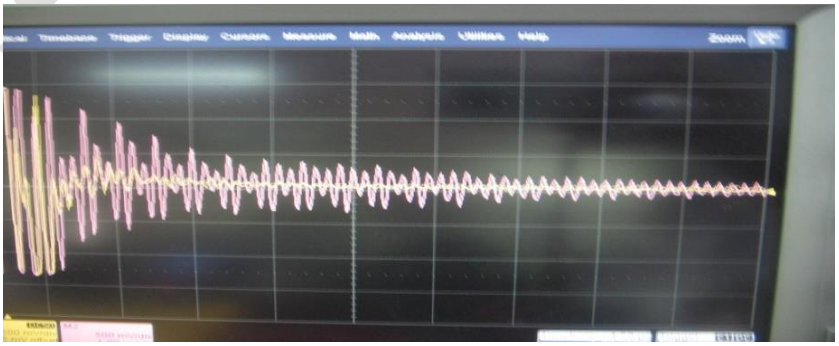


b) Oscilloscope image

From the Fig: b can clearly observe that the yellow signal (output signal) is following with the pink signal (reference signal), i.e., overlapping of signal (amplitude) taking place, then it is a de-bond point. Good bond point gives less miss match and minimum amplitude of reflections.



c) Good bond side graph of the casing



d) Oscilloscope image

From the Fig we can clearly observe that the yellow signal (output signal) is not following with the pink signal (reference signal), i.e., giving less signal (amplitude) then it is a good bond point.

CONCLUSIONS

From the experiments it is observed that

1. **Radiography** detected de-laminations and de-bonds in the form of contrast variations. But it is difficult to distinguish resin rich, resin-starved areas from delaminations and debonds in radiography because the contrast is not appreciable, difficult to resolve the characterization of defects and may require another NDE method to support the data observed in Radiography.
2. In **Infrared Thermography**, the de-laminations in High Silica Phenolic Composite liner, as well as, debonds in Maraging steel liner were clearly identified. Thermography is proved to be an excellent method for detecting the defects, for measuring the extent of area mapping at a very short time.
3. In **Ultrasonic testing,** defects were revealed. But it is difficult to find the size of the defect either by Pulse-echo testing or dry coupling technique.

It is observed that the higher the dB in ultrasonic testing (Through Transmission), the severe the de-lamination in radiography and the higher the temperature in Thermography (by double sided examination). Every NDE method has certain advantages and limitations, however, all the NDE methods are complimentary.

FUTURE SCOPE

Presently, delaminations and de-bonds are characterized using ultrasonic, radiography and Thermography. The same methods can be extended for characterizing the various types of defects. So that a comprehensive study is evolved.

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