Failure Detection of Different Composite Pressure Vessels

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Abstract. Pressure vessel can be dangerous if they are not properly maintained since they hold materials at high temperature or high pressure. Maintenance process of pressure vessels is an important aspect since it help to reveal the potential problems before they further developed. In present paper, two of the most used failure detection techniques are applied, the extensive experimental ultrasonic wave velocity US and X-ray CT on 75% wt. KF/epoxy laminates and 75% wt. GF/epoxylaminates with four different fiber orientations namely [±45°$_3$], [±55°$_3$], [±65°$_3$] and [±75°$_3$] are exposed to internal pressure load to compare the behavior of composite laminates and to detect the formed defects. The capability of ultrasonic wave testing and X-ray CT to obtain general information about the internal structure and to detect the defects was investigated. The internal pressure test show the superiority of [±45°$_3$] and [±55°$_3$]to resist internal pressure for both composite laminates. The ultrasonic wave velocity show simple fluctuating in wave velocity was for GF/epoxy laminate even before the internal pressure test whilesharp fluctuating appears after the internal pressure result especially for epoxy tube caused by sharp fracture fragmentations.The ultrasonic velocities can give information about the crack existence while the X-ray CT scan gives information about fibers orientation, fibers empty places and the apparentfractures.

Keywords: Ultrasound wave velocity, X-ray CT, detection, composite, pressure vessel.

Introduction

pressure vessels manufactured by filament wound technique are containers have the ability to withstand high pressuresand widely used in different applications as aerospace and military applications such as the rocket motor casings , air bottles, pipe lines, storage tanks etc.[1]. as the pressure vesselswithstands loads, composites bear tensile stress that's improve to form matrix cracks,gaps, and fiber–matrix degumming. The damage developing is dangerous and can be lead to vessel leakage (2). As well as the production of filament wound composites may introduceseveralof defects during processing like foreign inclusions, fiber misalignment that could occur when the fibers are laid up and fibers misalignment in the same layers or between layers. These defects may lead to delamination between layers either in production or in service(3).Several techniques have been proposed to explore these defects. The common used techniques areacoustic emission (AE), pulsed eddy current, X-Ray technique, thermography, and ultrasound test. These techniques allow to detect defects without damage during production or in the context of maintenance(4).

Ultrasonic is non-destructive technique used to examine the inner structures in different planes. It is possible to resolve structure layers by short ultrasound pulses and measure the dimensions structure in the depth direction(5). The information formed by ultrasonic signals can be analyzed in the terms of ultrasound velocity, ultrasound wave attenuation or structure noise(6). On the other hand, X-ray CT scan is nondestructive technique used to study the detailed defects of internal structure. This technique was first used in designing the medical CT device because the composite materials have similar composition to the human bodies (7). parallel cracks to the radiation beam or smaller cracks than the resolution are difficult to detect. For effective detection, the defects size must be 2% minimum of the thickness of the material. (8)

Several researcher studied the efficiency of ultrasonic technique in detection defect location and size,Haiti's(9) and Hussein Taher (10), succeed in specifying the size and the defect's location using C-scan techniques of composite materials. Zoran Bergant (11) disable to examine the defect depth. However, succeed with defect size. Johann Kastner, (12) and Xueshu Liu (13) used X-ray computed tomography for the characterization the size, shape and position of the pores as well as other defects of fiber-reinforced composites, Ahmed Arabi Hassen, (14) and AG Stamopoulos (15)presented works concern with identifying defects and porosity by X-CT.

This paper presents two techniques to detect and characterize the appeared defects results from exposing to internal pressure load on the Kevlar composite laminates and glass composite laminates. The Ultrasonic wave velocity and X-ray CT methods are th most used techniques in the controlling of composite materials.

Experimental Study

Materials and Preparation. The E-glass fiber Roving continuous product of Hebei Yuniu Fiberglass manufacturing Co., Ltd, and Kevlar fiber from Hitex® insulation & composites are mixed with Sikadur-52 LP (IN) Epoxy resin and Hardener (80:20). The Prepared resin was deposited into the resin bath tank. The process at desired parameters was began by loading the motion codes to filament wound machine shown in Fig. 1.

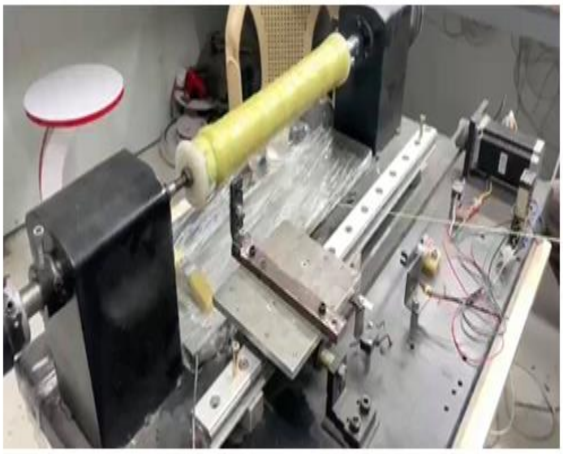

Fig. 1: The filament wound machine construction and elements.

The test specimens that are employed with diameter 50 mm, length 300 mm and the thickness ranged from 0.8 to 2 mm. Specimens of GF/epoxy andKF/epoxy at different winding angles $[\pm 45°_3]$, $[\pm 55°_3]$, $[\pm 65°_3]$ and $[\pm 75°_3]$ are employed as shown in Fig. 2. In addition to pure epoxy tube was manufactured for the comporision purpose.

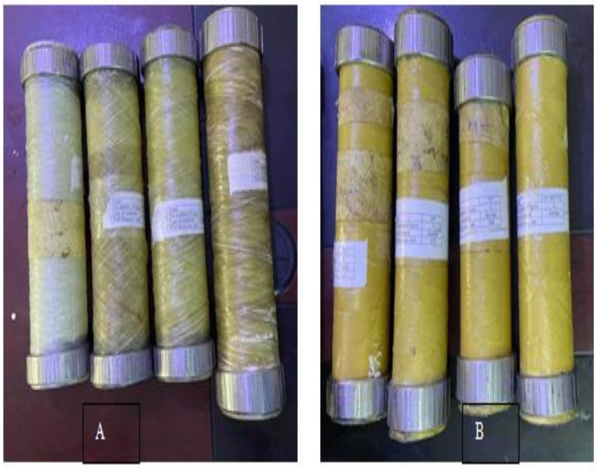

Fig. 2: A): GF/epoxy laminates, B) KF/epoxy laminates.

Test Setup

Internal Pressure Behavior. Internal pressure tests are performed according to ASTM D-1599 14e¹(16) standard by Hydrostatic Pressure Tester provided by Qulitest.The samples filled completely with water and the Pressure is applied and increased uniformly and continuously, until the test ends. The specimen are exposed to internal pressure by 100 bar. The internal pressure induces defect such as leaks.

Ultrasound Wave Velocity Test. The ultrasonic wave velocity test use the high frequency, high energy ultrasonic wave to investigate the general structure of the composite. Ultrasound wave velocity test achieved by placing sensors on both sides of the samples with two position a) vertically b) horizontally as shown in Fig 3. Special oil is placed between the transmitter and receiver power generator and the surface of the sample to reduce friction and improve the transmission and reception of ultrasound without waste of energy.

The velocity can be obtained by measuring the transit time from the emitting transducer to the receiving transducer. So that the velocity can be calculated by measuring the propagation length and the transit time in Eq. 1(3)

$$v = L/\Delta t \qquad (1)$$

Where: *V:* ultrasound velocity. L: propagation length of the ultrasound wave between the emitting transducer and the receiving transducer andΔt: transit time.

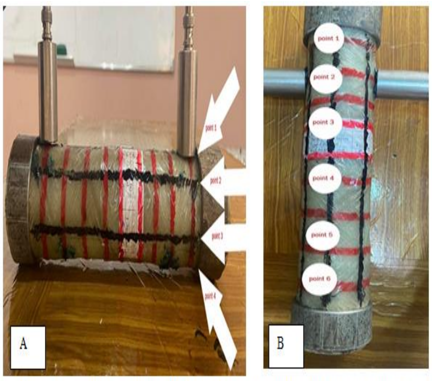

Fig. 3: A) Test procedure of measuring longitudinal wave velocity, B) test procedure of measuring shear wave velocity

X-ray computed tomography. A medical SIEMENS (SOMATOM Definition AS) machine is utilize to perform CT scans where the source and detector rotate around the stationary sample was used to scan the panel in a helical mode. TheSTRATON tube offers a spectrum of selectable tube voltages from 70 kV up to 140 kV. The images scanned with energy of 80 kV, eff. MAs. From 70 to 35 and scan time 12.5 s.

Results and Discussion

Internal pressure behavior. In order to determine the composite laminates behavior KF/epoxy laminates and GF/epoxy laminates with different orientation are subjected to 100 bar of internal pressure load. The result of internal pressure behavior of epoxy tube, KF/epoxylaminate and GF/epoxy laminate are shown in Fig 4.

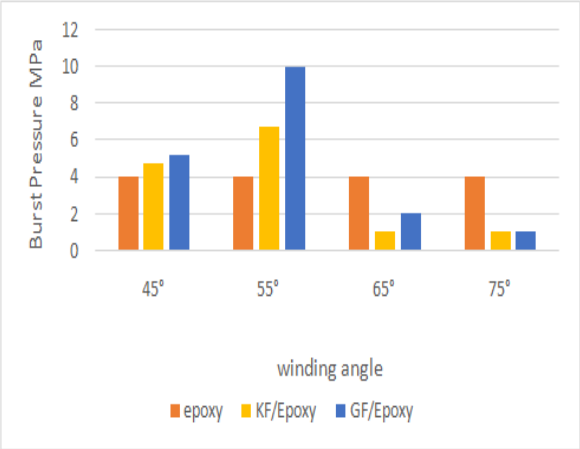

Fig.4: Internal pressure behavior of KF/epoxy laminates and GF/epoxy laminates.

Examining Fig. 4, it can be seen that the epoxy tube burst strength enhanced with reinforcing with fibers with [±45°$_3$]and[±55°$_3$] winding orientation. The epoxy tube exhibited a brittle fracture due to internal pressure load at 4 Mpa. as shown in Fig. 5. the burst pressure higher for winding angles [±45°$_3$]and[±55°$_3$] while for larger winding angle the burst pressure decrease for [±65°$_3$]and[±75°$_3$]for the both type of fiber composite laminates. However, the epoxy tube show higher pressure than [±65°$_3$]and[±75°$_3$] since epoxy tube has large thickness higher than all composite laminate. The failure mechanism appears as water leakage as shown in Fig. 6.

Fig. 5:Epoxy tube failure after burst pressure test.

Fig. 6: the water leakage results from burst pressure test.

Ultrasonic Wave Velocity Results. Results of the longitudinal and shear wave velocities of epoxy, KF/epoxy laminates and GF/epoxy laminates are shown in Fig 7 A), C) and Fig 8 A), C) It can be seen that ultrasonic longitudinal and shear wave velocities have close values for the epoxy and the two types of composite laminates referring to the homogeneity of all points for the epoxy and composite laminate tubes with no recording for voids, defects or fiber-empty places. Also it can be seen that GF/epoxy laminate have fluctuation wave velocity even before applying the pressure load Fig 7 C) and Fig 8 C).

After exposing the epoxy tube, KF/epoxy tubes and GF/epoxy tubes to internal pressure test as shown in Fig 7 B), D) and Fig 8 B), D) the ultrasound velocity test admits the determination of deformation and detection of cracks with different orientations, where the signal weakened each time they encounter the fibers layer due to formation of cracks caused by internal pressure loading which reduced the ability to detect defects in deeper layers.

Also it can be noticed that the velocity increased after internal pressure loading for epoxy, KF/epoxy laminate and GF/epoxy laminate due to changing of density due to formation of cracks due to burst pressure test. In addition to decreasing travel path that demands less time for the wave to reach to the opposite probe and that's refers to existence of cracks. The crack inception appear as velocity variation of the detectable sample. The velocity variation appears in the Fig. 7 B) and Fig. 8 B) after burst pressure test.

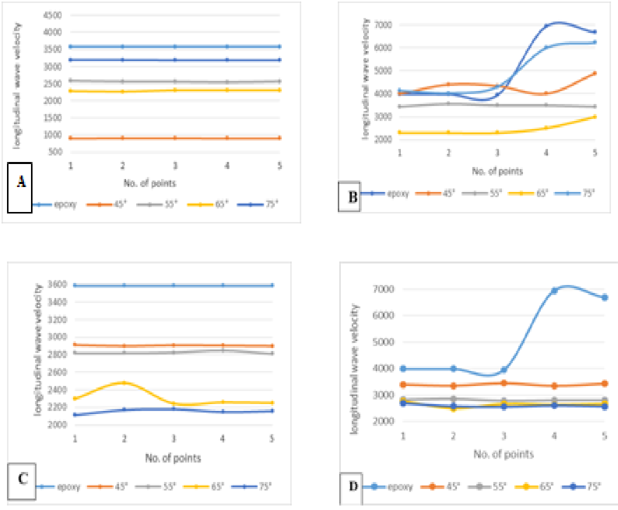

Fig. 7: Longitudinal ultrasound wave velocity of KF/epoxy and GF/epoxy laminate
A: KF/epoxy before burst pressure, B: KF/epoxy after burst pressure
C: GF/epoxy before burst pressure and D: GF/epoxy after burst pressure.

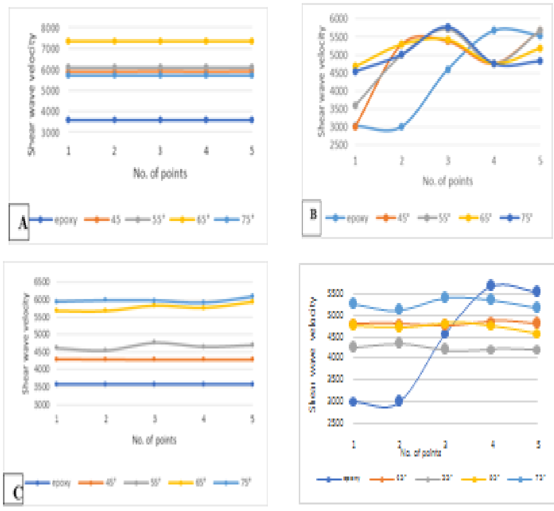

Fig.8: Shear ultrasound wave velocity of KF/epoxy and GF/epoxylaminate
A: KF/epoxybefore burst pressure, B: KF/epoxyafter burst pressure
C: GF/epoxy before burst pressure and D: GF/epoxy after burst pressure.

It can be mentioned that although the ultrasonic technique give remarkable information about the defects place. But, the exact shape or size of the defect could not be determined. From Figs. 7 and 8 it can be seen that GF/epoxy have more variation difference in both longitudinal and shear wave velocity than KF/epoxy laminates. This variation deference refer to semi-uniformity of the glass fibers in the epoxy matrix and that is apparently seen next in X-ray CT.

X-Ray CT Scan Results.The epoxy tube CT scan is shown in Fig. 9, where a distinct brittle fracture apparently seen in in CT scan.

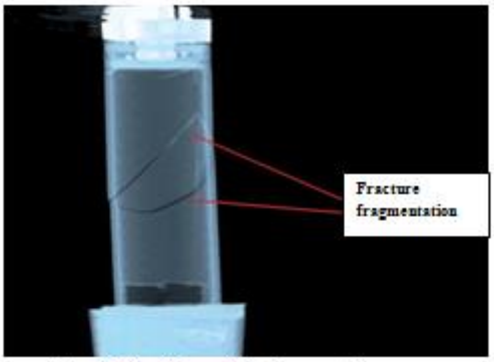

Fig. 9: The X-ray CT of epoxy tube.

Fig. 10 shows a X- ray CT of GF/epoxy laminate tubes with four different winding angle configurations; [±45°$_3$], [±55°$_3$], [±65°$_3$] and [±75°$_3$]. It can be seen that the glass fiber are clearly shown in CT scan. Although they have a complete patterns empty fibers path can be seen in the CT scan.

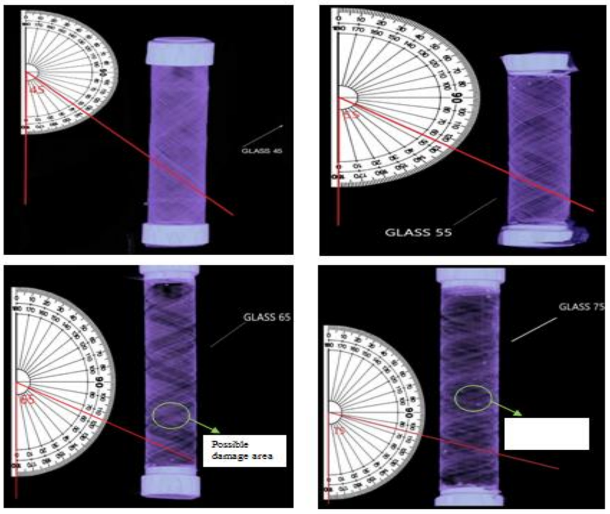

Fig. 10:X- Ray CT of GF/epoxy laminates.

The limited resolution of the medical CT affected the detectability of the composite laminates. Due to the rather small density difference between the KF and the epoxy matrix, the individual fibers are not clearly visible in the X-ray CT data as shown in fig. 11. The high X-ray tube voltage reduced the contrast between the Kevlar fibers and the matrix of the scanned composites. However, the glass fibers are more visible due to the large density difference between the GF and the epoxy matrix.From fig.11 it can be seen in KF/epoxy[±45°$_3$] that they have fiber spacing although they have a complete fiber pattern.

It was noticed that the X-ray CT technique has an advantage over the ultrasonic wave velocity in detecting fiber orientation and misalignments due to the high attenuation of the composite materials that was clearly detected by the X-ray CT-scans. Nevertheless the CT-scan could not identify the defects shape that formed during internal pressure test due to the small size of the leak.

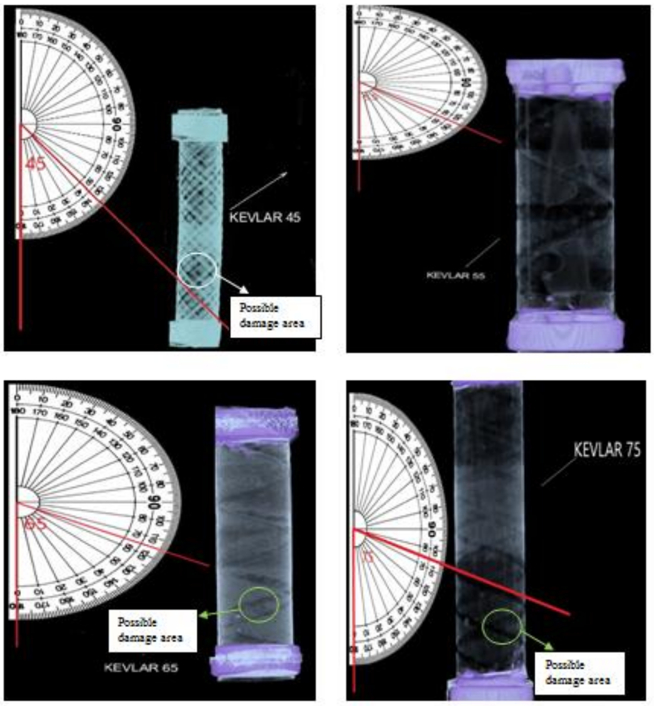

Fig. 11: X-ray CT of KF/epoxy laminates.

Conclusions

The present study investigated the efficiency of the ultrasound pulse scan and X-ray CT methods for detecting defects in KF/epoxy laminates composite and GF/epoxy laminates that manufactured by filament winding machine with four different orientation $[\pm45^\circ_3]$, $[\pm55^\circ_3]$, $[\pm65^\circ_3]$ and $[\pm75^\circ_3]$ before and after being exposed to internal pressure load. The main conclusions of this study are:

- All the composite laminates show approximate uniform wave velocity referred to good fabrication.
- The Kevlar fiber composite laminates exhibited more burst strength than glass fiber.
- The defects results from burst pressure appeared as leaks.
- The Ultrasonic wave velocity test is more efficient in detection the leaks place but not the shape and size of leaks.
- In X-ray CT the leaks position detection is less accurate due to small size of leaks, however, the fiber orientation and fiber empty places are clearly detected.
- The X-ray CT is much more efficient and clearly forGF/epoxy laminate than when inspecting the KF/epoxy laminate ones.
- The X-ray CT distinctly appear the fracture of epoxy tube.

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