The International Journal of Business Management and Technology, Volume 6 Issue 3 May-June 2022
ISSN: 2581-3889

Research Article Open Access

Testing of the Structure of Carbon Fiber Reinforce Polymer Composite Panels Due to Blast Explosion Using C-Scan Ultrasonic Test Aid

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Abstract*:* Ultrasonic testing (ultrasonic testing) utilizes high-frequency sound waves to detect damage to a material, composite or workpiece. This test is commonly used to inspect materials made of metal or plastic, as long as the material is not absorbent. In its application, ultrasonic testing uses a workpiece vibrating device called a probe. Ultrasonic waves emitted by the probe will vibrate the atoms in the test material or workpiece. The most ideal method for inspecting defects in composites is the immersion method. The size of the immersion tank must be considered as well as possible in order to accommodate the test object of the required size. C-Scan provides data about the location, size, and shape of the defects that occur, besides C-Scan with very high resolution can produce very detailed images. The specimen tested was a laminated composite made of C-glass/epoxy with material properties. The specimen is in the form of a square with a size of 150mmx100mm (referring to ASTM-D7136-12), the test specimen has a thickness of 2.5 mm and is given an impact load with an energy of 11.3 Joules. Stacking sequence of the test specimen, marking and representing the orientation of the fibers in a single layer (layer) of woven composite. After being given an impact load, there is damage in the form of delamination on the plate. plate damage can be detected by back light and numerical simulation.

Keywords: ultrasonic, material and composite

I. Introduction

Composites are a promising new development. Composites have other advantages, such as forming *complex* shapes and being light and strong. Composites, unfortunately, are extremely vulnerable to *impact* loads. *Low-velocity impact* (LVI) is a type of hazardous impact on composites during manufacturing, operation, or routine inspections. Damage caused by LVI is not visible to the naked eye, but it can significantly reduce the composite's strength, particularly its compression strength.

The detection of BVID damage in composites has been the subject of numerous studies. A. Fahr (1992) used an ultrasonic C-scan to inspect several types of damage to the composite in the study. Meanwhile, Byeongjin Park et al. (2014) used *ultrasonic scanning lasers* to conduct inspection studies on the delamination and debonding of composites. In his research, Park found that the inspection technique using *ultrasonic scanning lasers* has several advantages: it can be applied to extreme environmental conditions and results in high resolution. In Katunin's (2015) study, various NDI techniques were used to inspect composite damage. PZT *sensing*, *ultrasonic C-scan*, *thermography*, and vibration testing are the NDI techniques used by Katunin. Katunin discovered that *ultrasonic C-scan* inspection results in more precise damage detection: depth, size, and location, based on his experience with several NDI techniques. As a result, the *ultrasonic C-scan* damage inspection technique is suitable for use on multi-layer structures such as composites.

The C-Scan *presentation* is a more advanced version of the A-Scan and B-Scan displays. C-Scan provides information on the location, size, and shape of defects. Typically, the data displayed by the C-Scan is A-Scan data that has been processed. The C-Scan *presentation* will display the signal in the form of an *oscilloscope* in the A-Scan *presentation* with specific colours. C-Scan images with a high resolution can be very detailed. Figure 5 depicts an example of a C-Scan *presentation's* output. The results of ultrasonic testing on a composite plate subjected to a *low-velocity impact* (LVI) load are shown in Figure 5.

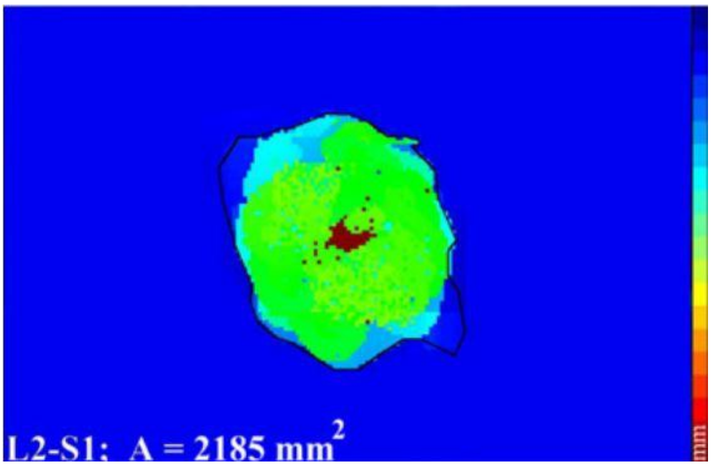


Figure 1. C-Scan *Presentation* Results (E.V. Gonzalez et al., 2010)

C-Scan for composites is typically performed with an automatic scanning system in which a computer controls the *probe* movement.

II. Research Methods

An inspection tool that can display the location, shape, and size of defects caused by LVI in composites is required to avoid potential dangers. As a result, in ultrasonic testing, C-Scan is the most effective type of display for detecting defects. The following are the ultrasonic C-Scan testing methods commonly used for composite structures, based on the *coupling* mechanics used:

2.1 Immersion Method

This method uses water to replace the *couplant* as a "connector" between the *probe* and the test object. The immersion method involves immersing the composite structure in an *immersion tank*. The *transducer* is submerged above but not in contact with the test object.

2.2 Squirter Method

Like the immersion method, the squirter method uses water as a *couplant*. In this method, water is sprayed on the test object as the *probe* moves during the scanning process. A *through transmission* mechanism is always used in the *squirter* method (Matthias SCHWABE et al., 2010).

2.3 Non-Immersion Method (Portable Probe)

The portable probe method is the most traditional of the three options. The *couplant* in this method is usually in the form of a gel applied to the specimen's surface before the inspection. This method is highly reliant on the operator's expertise, and it cannot detect damage to every *ply* laminate (only general damage can be seen). Even so, this method has the advantage of being *portable* so that the test object can be directly tested in the field.

2.4 Comparison

Explain the inspection methods commonly used for composites in points 2.1 - 2.3. Each of the three methods has its own set of benefits and drawbacks.

Table 1summarizes and quantifies the advantages and disadvantages of these methods:

Table 1. Comparison of Ultrasonic C-Scan Methods forComposites

	Criteria	Immersion Methods	Squirter Methods	Portable Probe Methods
	Detection of defects in each ply laminate	5	0	0
	Couplinguniformity	5	5	2
	Signal quality against noise	4	2	4
	Resistance to attenuation	5	5	2
	Test object sizelimit	2	5	5
	Test object shape limit	5	2	5

Total	**26**	**19**	**18**

The immersion method is the ideal method for inspecting defects in composites, according to the comparison and quantification performed in

Table **1**. In order to accommodate the test object of the required size, the *immersion tank's* size must be carefully considered.
The probe frequency, type, and size are factors to consider when inspecting composites with ultrasonic testing. The frequency of probes is inversely proportional to the presence of a *dead zone* (the zone where defects cannot be detected). Because the *dead zone* size can affect the minimum thickness of the test object that can be accurately inspected, high-frequency *probes* have a smaller *dead zone*.

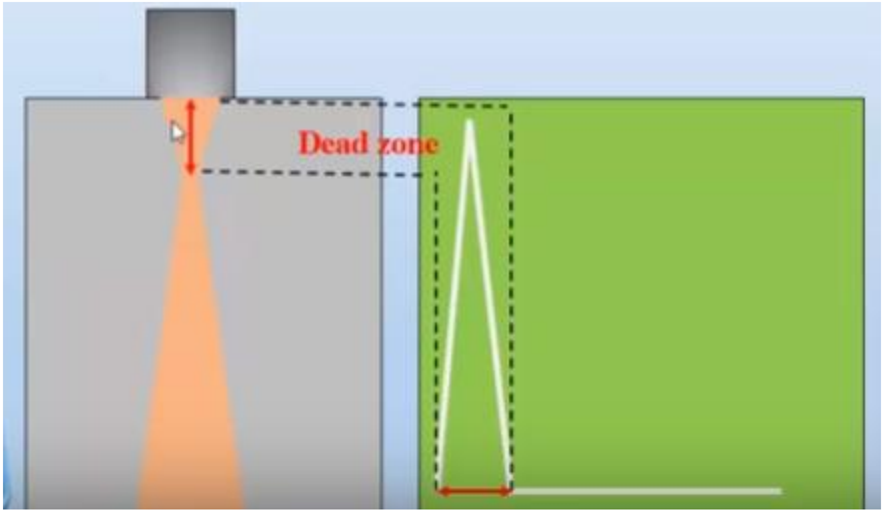


Figure 2. Dead Zone (El Mustapha Ben, 2015)

Because the amount of defects that can be detected is dependent on the size of the *probe* diameter, the size *probe* plays an important role. Another essential factor to consider is the *probe's* type. Is a *conventionalprobe* or a *phasedarrayprobe* to be used? *Conventional probes* are unquestionably less expensive than *phased arrays probe*. Despite their high cost, *phased array probes* will provide a much better response *through-thickness* than *conventional probes*.
2.5 Research ImplementationStages
The research implementation phase is the core of research activities on testing the damage to composite materials caused by explosions. The stages are as follows:
It is necessary to prepare scenarios when validation is carried out during research procedures so that this method can be carried out in real terms for experimental validation. The following preparations must be made:
2.5.1 Prepare specimens with dimensions of 400 x 400 mm
2.5.2 Prepare test equipment for specimens with the expectation that the test area used for testing is 250 x 250 mm

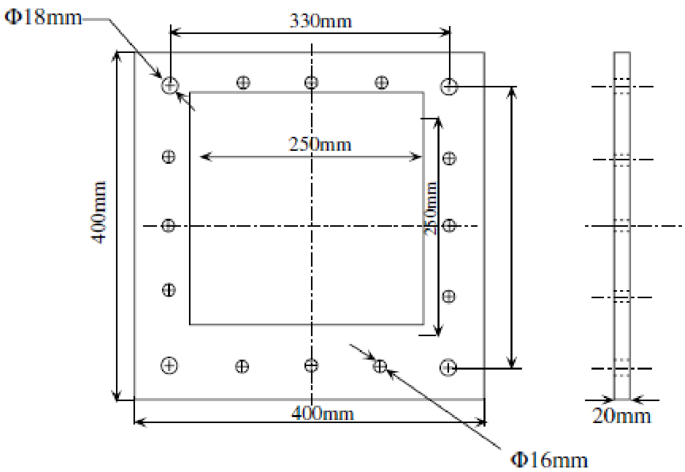


Figure 3. Test Specimen

III. Results and Discussion

Not many ultrasonic C-Scan tools are dedicated to detecting defects in composites in Indonesia. PT Dirgantara Indonesia and PT PupukSriwidjaja are two Indonesian companies that own the ultrasonic C-Scan tool. PT Dirgantara Indonesia has been developing composite-material fighter aircraft in recent years. To ensure that the composite structure used is of high quality. This tool uses the squirter method with *through transmission* mechanism. Detailed images of the C-scan ultrasonic test equipment owned by PT Dirgantara Indonesia are presented in **Error! Reference source not found.**4.

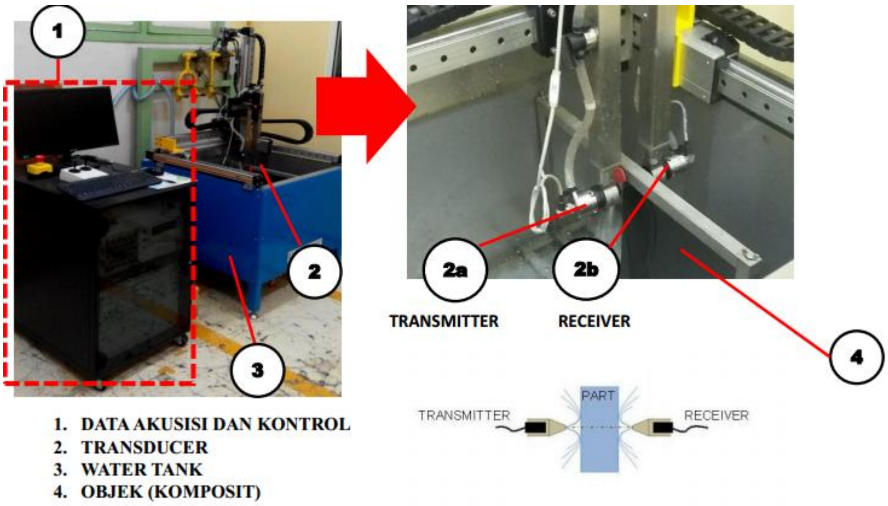


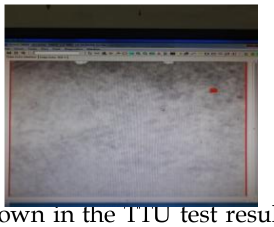
Figure 4.*Through Transmission Ultrasonic* (TTU)
owned by PT DI (Handoko and HardinalHadi, 2018)

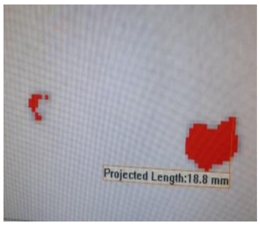
A *conventional probe* with a frequency of 5 MHz is used in the TTU device of PT Dirgantara Indonesia. The TTU tool can only detect damage on the surface of the laminate and cannot detect damage in all layers. **Error! Reference source not found.**5depicts the inspection findings of PT Dirgantara Indonesia's TTU equipment.

Figure 5. Defects Detected Using TTU PT DI

Error! Reference source not found.depicts damage caused by a *blast* load on 12-layer carbon fibre.

Table 2. Damage due to blast on 12 layer carbon fiber

No	Material		Number of Layers	TNT Weight (mg)	Distance (mm)	Thickness (mm)	TTU Test Results
	Fiber	Carbon					
1	Fiber Glass		10	60	1000	1,8	 As shown in the TTU test results in the image above, fiberglass can withstand *blast* loads and has no delamination.
2	Fiber Glass		12	80	300	2,4	 The results of the TTU test show that fiberglass material laid up by hand has delamination (loss between fibers) and voids (air voids) in the specimens that have been tested, as shown in the image above. Finally, the *blast* explosion caused damage to the material, but there was no visible damage after the explosion.
3	Fiber Glass		12	100	300	2,1	 The results of the TTU test show that fiberglass material has delamination (release between fibers) and voids (air voids) that are extremely high, causing the material to be damaged.
4		Fiber Karbon	5	100	300	1,90	

		Prepreg					The TTU test results show that there is carbon material delamination on the lower right, which is caused by the *blast* pressure from the TNT explosion source with a diameter of 18.8 mm, as shown in the image above. 

3.1 Ultrasonic C-Scan

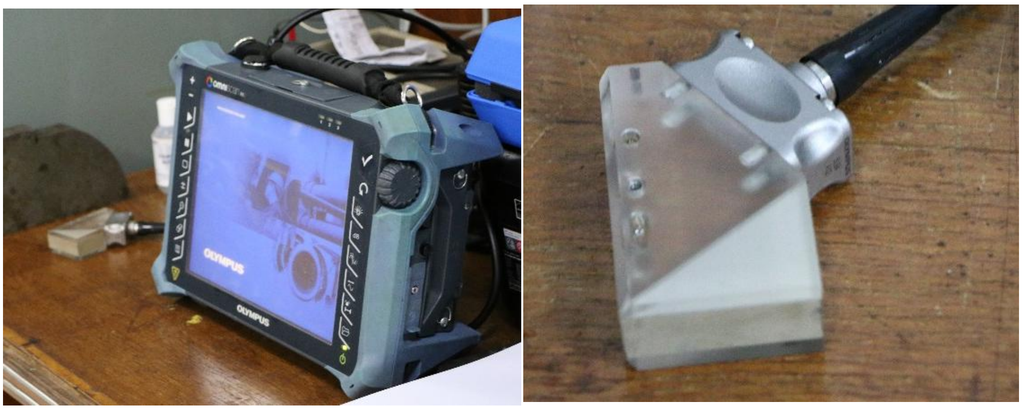
Ultrasonic C-Scan at 5 MHz with *phased array probe*. The *phased array probe* is a cutting-edge technology incorporating multiple crystals into a single *probe*. The tool's shape is depicted in **Error! Reference source not found.**6.

Figure 6. Ultrasonic C-Scan with a phased array probe

They tested composite specimens with BVID (*barely visible impact damage*) using their C-scan. In addition, this research aims to determine the best inspection method for detecting BVID in composites.
Metals have different properties than composite materials. As a result, to properly detect BVID damage in composites, special tools with different specifications are required to detect defects in metal.

3.2 Specifications of Ultrasonic C-Scan tool

Olympus MX2 brand ultrasonic C-Scan. A *phased array probe* with a frequency of 5 MHz is used in the tool. **Error! Reference source not found.**7depicts this tool.



(a) (b)

Figure 7. C-Scan: (a) Display Unit, (b) *Phased Array Probe* Angle

Error! Reference source not found.7 shows some of the test equipment commonly used to detect damage to *steel* components.**Error! Reference source not found.**8shows a *standard reference block* (SRB) type IIW (*international institute of welding*) used to calibrate the tool.

Figure 8. SRB Type IIW (Admin, 2019)

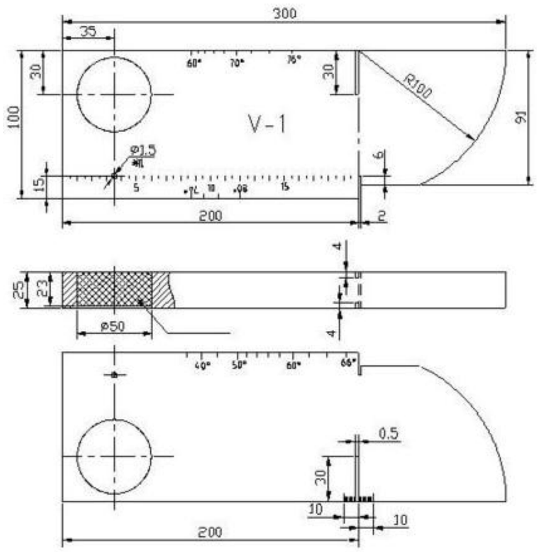


Figure 9. Technical Drawing of SRB Type IIW (Admin, 2019)

Error! Reference source not found.8 depicts an SRB made of 1016 *steel*. The thickness of the SRB is 25 mm, according to the size details shown in**Error! Reference source not found.**9. The test equipment is placed perpendicular to the thickness of *steel* with a thickness of 25 mm to calibrate the tool detection capability. Different thickness surfaces or materials are required to calibrate the capability of tools at different thicknesses.A polymer-based component of the SRB can be seen in**Error! Reference source not found.**8. The tool's ability to detect a thickness of 50 mm in *steel* is calibrated using parts made of this polymer.

3.3 Composite Specimen Specifications

The specimen to be tested is a C-glass/epoxy *laminated composite* with the *material properties* listed in Table 3. As shown in Figure 10, the specimen is in the shape of a square with dimensions of 150mmx100mm (as per ASTM-D7136-12).

Table 3. Properties of Test Specimens

Density		$1700\ kg/m^3$
Intra-laminar	Elastic properties	$E_1 = 110GPa, E_2 = 7.8\ GPa,$ $\nu = 0.32,$ $G_{12} = G_{13} = G_{23} = 4\ GPa$
	Strength	$X^T = 2093\ MPa, X^C = 870\ MPa,$ $Y^T = 50\ MPa, Y^C = 198\ MPa,$ $S^L = 104\ MPa$
	Fracture energy	$G_{ft} = G_{fc} = 10N/mm,$ $G_{mt} = G_{mc} = 1\ N/mm$
Inter-Laminar	Elastic properties	$K_n = K_s = K_t = 850\ MPa$
	Strength	$T_n = 3.3\ MPa, T_s = T_t = 7\ MPa$
	Fracture energy	$G_n = 0.306\ N/mm$ $G_s = G_t = 0.632\ N/mm$

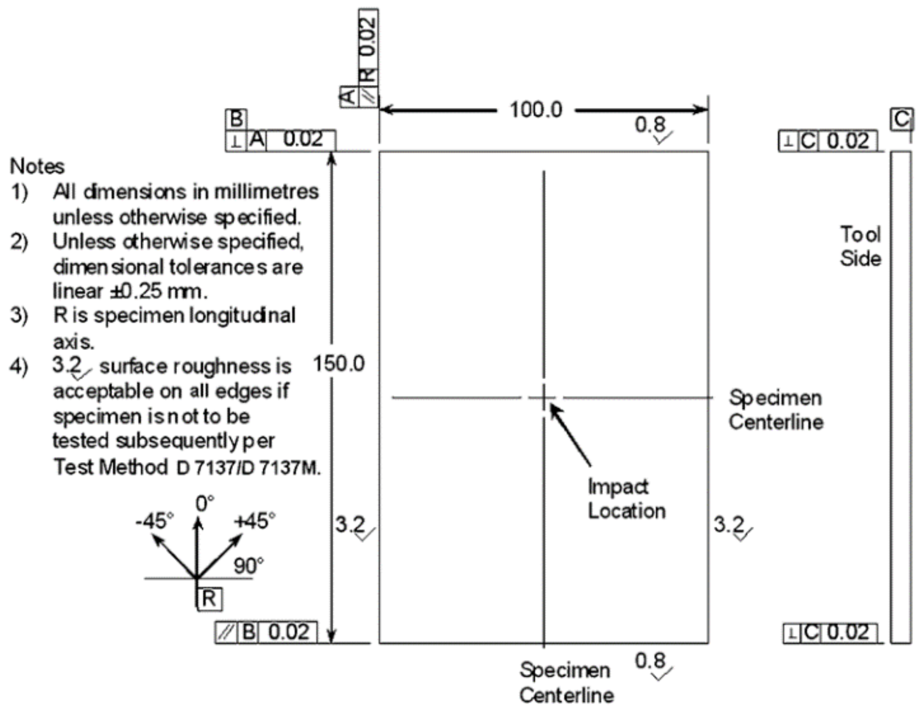


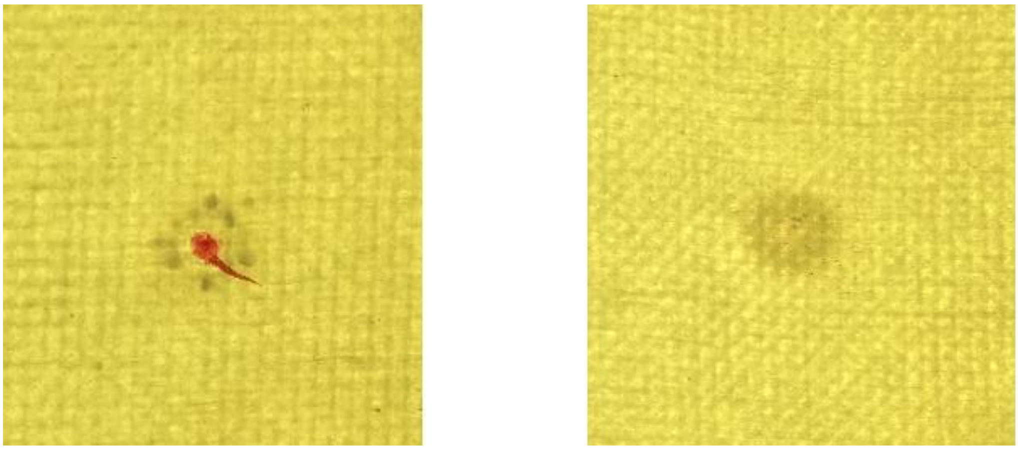
Figure 10. Specimen for Drop Weight Impact Test (ASTM, 2005)

An *impact* load of 11.3 Joules is applied to the test specimen, which has a thickness of 2.5 mm. Table 4 shows the *stacking sequence* of the test specimens. The orientation of the fibers in one layer of *woven* composite is represented by the markings (+45/-45) and (0/90).

Table 4. Stacking Sequence of Test Specimens

Name	Stacking sequences
Blocked Layer 1 (Impacted side)	$[0/90]_2$
Blocked Layer 2	$[45/-45]_2$
Blocked Layer 3	$[0/90]_2$
Blocked Layer 4	$[45/-45]_2$
Blocked Layer 5	$[0/90]_2$
Blocked Layer 6	$[45/-45]_2$
Blocked Layer 7	$[0/90]_2$
Blocked Layer 8	$[45/-45]_2$
Blocked Layer 9	$[0/90]_2$

The plate suffers damage from delamination after being subjected to an *impact* load. *Backlight* detection of plate damage is shown in**Error! Reference source not found.**11.**Error! Reference source not found.**12 depicts the results of numerical simulation-based plate damage detection.



(a) (b)

Figure 11. Damage to Specimen detected by *back light*:
(a). Impacted Side and (b) Back Side

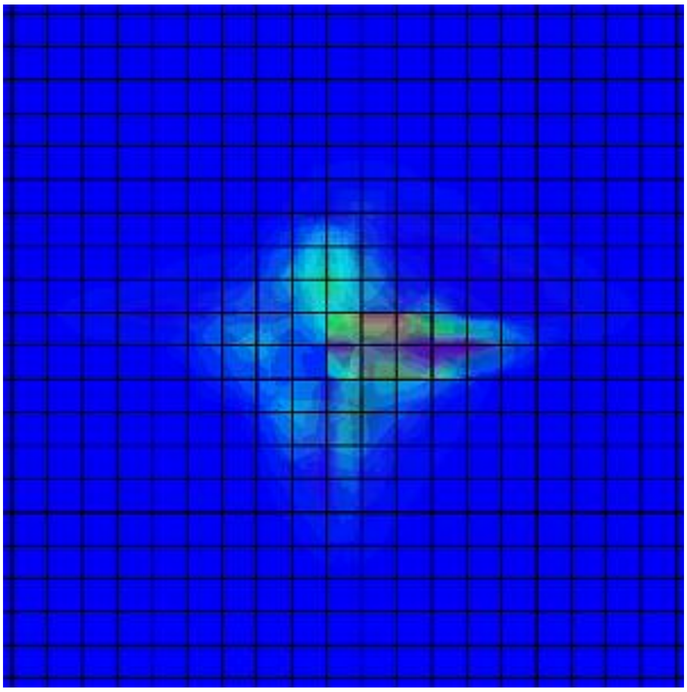
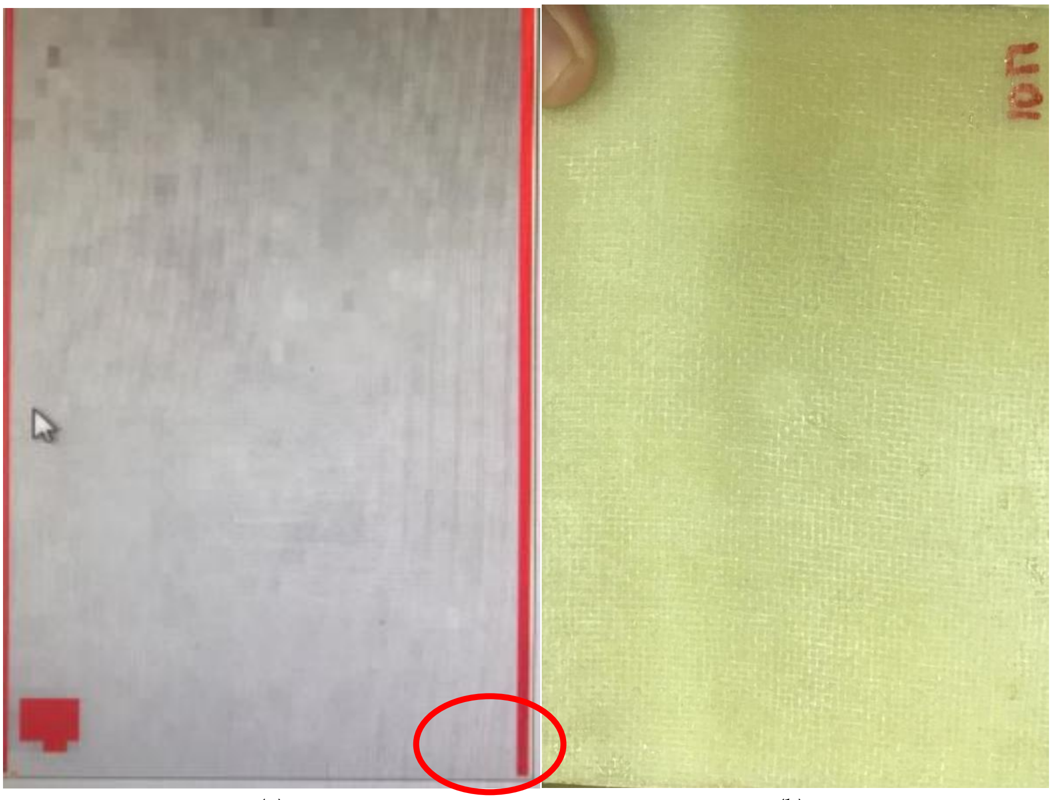


Figure 12. Total Delamination on Plates Detected by Numerical Simulation (size 30x30 mm)

3.4 Inspection Results with *Ultrasonic Test*

depicts the results of the inspections conducted with TTU.



(a) (b)

Figure 13. (a): Inspection Results with TTU, (b): Test Specimen

TTU inspection did not yield good results, as shown in
3. Surface defects caused by resin cracking when the specimen is removed from the *baking pan* (see red circle in

3 (b))are visible in the lower-left corner of
3 (a).

The results of the *phased array probe* inspection were slightly better than TTU. Regrettably, the C-Scan ultrasonic tool is frequently used to detect damage to *steel* components. The test results from the tool for composite defect detection are still not very accurate because the defects in the composite are located in the tool's *dead zone* (*dead zone* explanations see **Error! Reference source not found.**2). The results of the Ultrasonic C-Scan probe phased array inspection on composite specimens are shown in Figure14.

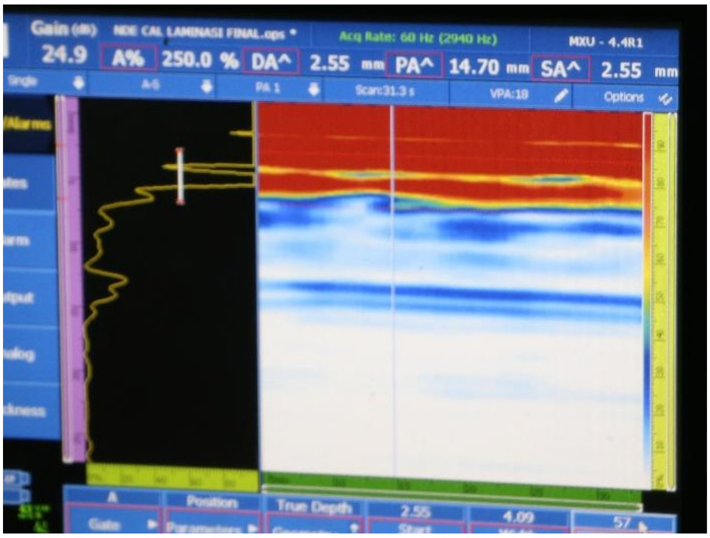


Figure1.*Phased Array* C-Scan Inspection Results on Composite Specimens

Figure114 shows that the inspection results on the composite have a significant amount of *noise*. In contrast to composites, steel tests produce extremely accurate results (see **Error! Reference source not found.**15).

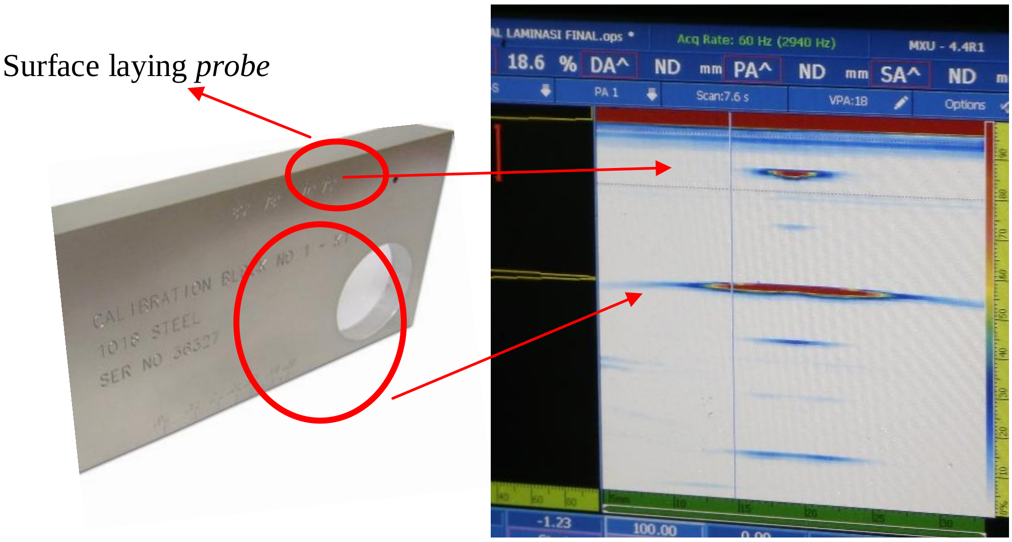


Figure 15. Results of *Phased Array* C-Scan Inspection on *Steel*

The proprietary *Phased Array* C-Scan on steel can provide excellent inspection results, particularly in the *through-thickness* direction, as shown in **Error! Reference source not found.**15. There are two visible artificial defects (small circle and large circle), which the *Phased Array* C-Scan tool can detect, and their depth. These findings show that the tool is very good at detecting flaws. The *probe* frequency, however, is ineffective for detecting defects in composite specimens. Several methods can be used to improve composite accuracy, including using a *probe* with a frequency lower than 5 MHz or a composite specimen with a thickness greater than 6 mm.

IV. Conclusion

The *phased array probe* is a product of extremely advanced technology. Using a conventional *probe* to detect BVID damage to composites is sufficient. However, a *portable probe* cannot detect damage to the composite in each layer when using a different inspection technique since the *portable probe* must make contact with the *coupled* specimen during the inspection process. In order to avoid *dead zones*, thicker specimens or devices with a lower frequency are needed. As a result, the *through-thickness* area that can be inspected is constrained. A specimen with a thickness of at least 6 mm is needed, and the *immersion* method utilizing a water medium is the optimum way to find the BVID in each composite layer. Between the *probe* and the specimen, water acts as a "couplant." The *through-transmission* approach is not advised for BVID detection in composites because this method also cannot show damage to each layer. Inspection can be carried out using the non-contact method with the specimen submerged, allowing for the detection of BVID at each layer. Additionally, only components with specific geometries can be used *through-transmission* method.

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