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The Evaluation for Accuracy of Non-destructive Testing (NDT) in Ultrasonic Inspection on Stainless Steel Material by Ultrasonic Testing Thickness Measurement

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Abstract: In this paper, the thickness of Stainless Steel plates was measured and analyzed using an ultrasonic testing thickness measurement using pulse-echo method. Factors in thickness measurement had a particular influence on the thickness measured on coupling agent, blasting effect, and different types of probes. The accuracy of UTTM technique was compared with ruler and digital vernier calliper. For effectiveness, the surface of samples were also cleaned with sand blasting process to observe the ageing effect on the specimens. The results of all 30 days revealed that, of all the devices used to measure thickness, the vernier calliper has the best percentage of accuracy (close to 100%), while the UTTM by double crystal probe has the highest (98%) when compared to single crystal probe. To summarise, the UTTM method can measure the thickness of any material in any circumstance, and the results have proven to be as accurate as a ruler and a Vernier calliper. Even when access is not accessible from both sides, UTTM produces the closest answer to the actual measurement.

Keywords: UTTM Method, Couplant, Sandblasting, Ageing Effect

1. Introduction

Generally, because of the outstanding corrosion resistance and mechanical qualities, stainless steel structures have a broad range of applications. Current research on stainless steel structures focuses mainly on material properties and member behaviour. Stainless steel provides excellent mechanical capabilities as well as outstanding corrosion resistance and architectural attractiveness. Stainless steel would be the appropriate construction material in corrosive industrial or natural environments such as paper mills, maritime constructions, including buildings with a high architectural aesthetic requirement, or a long design life like the sea bridge [1].

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Alternative non-destructive verifications technique (NDT) called Ultrasonic Testing for the metals are effective testing for detecting the defect without any damage disturbance of the components [2]. Non-destructive testing -Ultrasonic testing (NDT-UT) can determine the material thickness, likewise, detecting the flaws of materials by utilizing the sound waves where it depends on the electronic transducers that transmit sound waves of high-frequency to materials [3]. The key characteristics of the properties of the metal materials reveal since the sound waves bounced the images that show the defects. NDT-UT can be divided into two general methods which are Ultrasonic Testing Thickness Measurement (UTTM) and Ultrasonic Testing Flaw Detection (UTFD).

Thickness measurement of the tested parts can also necessitate the use of specialized equipment, such as vernier callipers, which can be utilized if the tested parts are sufficient in size for the vernier callipers. Plus, a ruler which scale is limited to a certain length and size. In any case, Stainless Steel parts come with different characteristics such as microstructure, particle orientation, and heat treatment condition of the material. These can affect the sound velocity in the material during UTTM due to the stainless steel exposing several conditions and environment [1]. Hence, they will be able to be examined and compared using both traditional methods and ultrasonic processing.

As more of a consideration, NDT can be a better technique than the other approach because it can be used to assess and track the thickness measurement, condition, and specification of the Stainless Steel structure before or during any procedure without damaging any components, devices, or equipment. Furthermore, NDT is not required to access both end sides most of the long pipe system. This study will evaluate the accuracy of UTTM in measuring thickness on Stainless Steel in general.

2. Materials and Methods

Equipment for the UTTM test was prepared to allow direct interaction with the data gathered. In this subtopic, the various types of equipment with standard and specifications used in this research were explained

2.1 Testing specimens

A big Stainless Steel block was fabricated using a machine that divides the final product into 18 smaller pieces. This block was fabricated using hydraulic swing beam shears. These procedures are critical because they need a synchronized diameter cut with a 1.5mm thickness on all workpieces. In this thickness measurement by ultrasonic testing technique, one types of metal are listed out to be inspecting in different parameters. There are 18 pieces of stainless steel which come in shape of plate. Figure 1 shows the Stainless Steel plate.

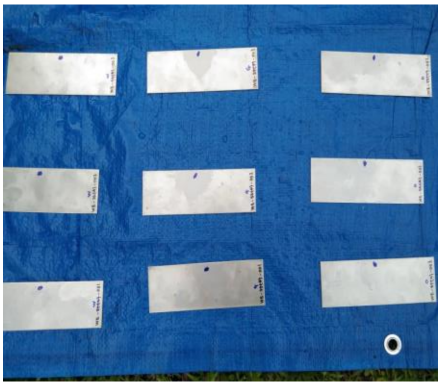


Figure 1: Stainless steel plates

2.2 Methods

To carry the objectives of this study, the thickness measurement of stainless steel is measured by using ruler, vernier calipers and UTTM method. The sample were sand blasted to analyze the rigidity of the material and exposed to environment in interval of 15th day for 30 days before measured its thickness for the ageing effect testing. UTTM method is implemented different types of 0^{o} probe, single and twin crystal probe with different types of couplant (Oil, Grease, Water).

In this experimental inspection on thickness measurement, ultrasonic transducer is calibrated by using 8 Step 304 Stainless Steel calibration block as described in the Table 1 as refer to standard EN ISO 16946:2017, specification for step wedge calibration block.

Stainless Steel calibration block as shown in Figure 4 was prepared by the milling process using the CNC milling machines based on the specification and dimension as stated in the Table 1.

Table 1: Description of calibration block used.

Description	Specification	Size (mm)
Specification for step wedge calibration block It requires high precision (max. -0.02 on the step thicknesses) and full traceability on all treatments and inspections.	• 8 Step wedge Block 304 Stainless steel • EN ISO16946:2017 is a new standard for Non-destructive testing - Ultrasonic testing - Specification for step wedge calibration block	Comes in thickness of 1.0mm, 2.0mm, 3.0mm, 4.0mm, 5.0mm, 6.0mm, 7.0mm, and 8.0mm Face: 15mm × 15mm

Figure 2: Custom 8 Step wedge block 304 stainless steel

2.3 Equations

The measurement of percentage accuracy on the evaluation of theoretical value and experimental value is calculated as shown in Equation 1.

$$Percentage\ accuracy = \frac{Theoretical\ value}{experimental\ value} \times 100\% \quad \text{Eq. 1}$$

3. Results and Discussion

3.1 Results

Table 2 displayed the summarization of the UTTM method by different probe for 0th, 15th, and 30th day of specimen exposed. Twin crystal probe with grease as couplant frequently gave the most accurate reading compared to the single crystal probe.

Table 2: Summarization of the UTTM method by different probe for 0th, 15th, and 30th day of specimen exposed.

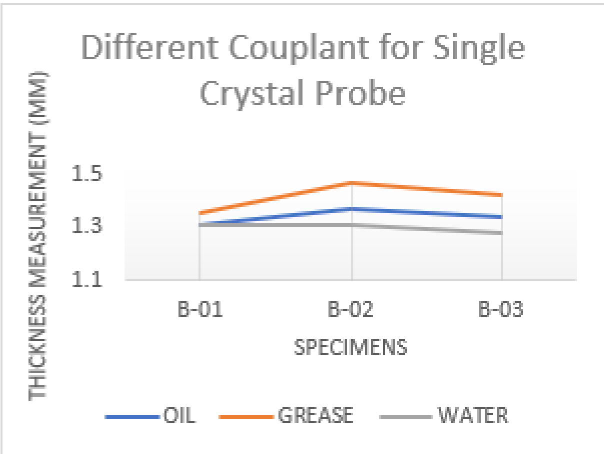
	DAY	PROBE	ACCURATENESS (%)	COUPLANT
BLASTING STAINLESS STEEL PLATE	0	Single	93.33	Oil
		Twin	98.67	Grease
	15	Single	94.67	Grease
		Twin	98.47	Water
	30	Single	94.22	Grease
		Twin	98	Grease

3.1.1 Couplant analysis

Grease couplant frequently the best compared to oil and water as shown in Table 2. Grease may have the highest acoustic impedance due to the higher amplitude of BEW. As mentioned in a study, it is evident that the amplitudes of first back wall echoes increase with increasing acoustic impedances of couplant [4]. Therefore, the attenuation effect was maximal as attributed by the grease acoustic impedance properties. However, a study stated that despite having comparable acoustic impedance ratings, grease provided less frequency gain than the other couplant. This was due to its poor wetting qualities and the formation of air pockets upon contact with the steel plate samples [5]. Thus, grease cannot be validated as there may have errors while running the measurement. Figure 5 and Figure 6 shows the comparison of couplant for both types of probes on 30th day of inspection.

	Oil	Grease	Water
Accuracy percentage %	89.33	94.22	86.67

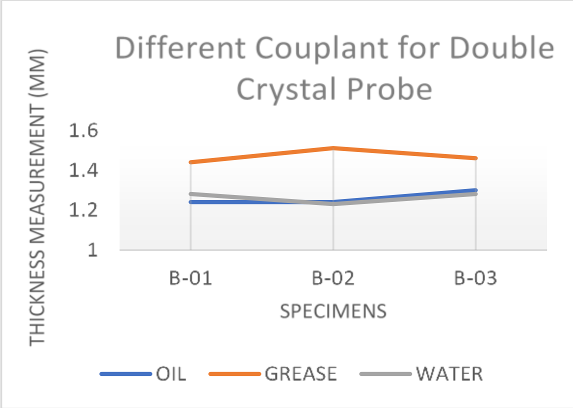
(a)



(b)

Figure 3: (a) Data for blasting samples based on different couplant with single crystal probe (b) The graph comparison based on different couplant with single crystal probe.

	Oil	Grease	Water
Accuracy percentage %	84.00	98.00	84.22



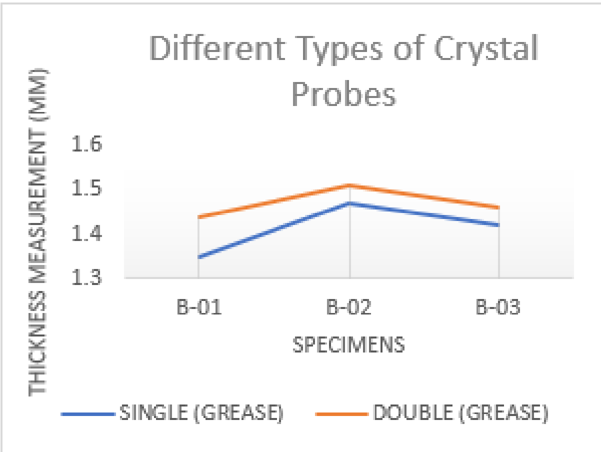
(a) (b)

Figure 4: (a) Data for blasting samples based on different couplant with double crystal probe (b) The graph comparison based on different couplant with double crystal probe.

3.1.2 Probe analysis

On each day of inspection, twin crystal probe obtained the most precise reading of thickness (around 98% to 99% of accurateness) as shown in Table 2. The probe setting of the twin crystal might be in the very best of its abilities while the single crystal probe had some error in setting procedure where sometimes the membrane of the probe contained air bubbles that can cause an incorrect thickness measurement on the Stainless Steel plate. Figure 5 shows the result of different probe on the last day of inspection.

	Single crystal (grease)	Double crystal (grease)
Accuracy percentage %	94.22	98.00



(a) (b)

Figure 5: (a) Data for blasting samples based on different crystal probes (b) The graph comparison based on different crystal probes.

In addition, twin crystal probe might have the maximum sensitivity compared to the single crystal probe. Sensitivity reduction of single crystal probe possibly because of probe wear. This issues was led to the increasing of surface roughness and tend to resulting in inaccurate measurement results [6]. The different probes obtained different accuracy because the calibration block might affect the scanning process as it was not achieving the standard due to no heat treatment procedure in the fabrication process which led to incorrect calibration procedure of the ultrasonic device. Thus, inaccurate calibration procedure can affect the accuracy of both single and twin crystal probe in displaying the data. Furthermore, the probe location error might influence the measuring results [7]. The aging effect after blasted had changed the thickness measurement of the specimens, which might cause the flat surface of the specimen to become uneven. Therefore, it is necessary to constantly inspect the thickness at the same point of location on the surface of specimens.

3.1.3 Different tools analysis

Table 3 displayed the summarization of 30 days experiment on comparison between different thickness measurement tools (UTTM, Ruler, Vernier Caliper).

Table 3: Summarization of 30-day experimental results

	DAY	TOOLS	ACCURATENESS (%)	COUPLANT
BLASTING STAINLESS STEEL PLATE	0	Single	93.33	Oil
		Twin	98.67	Grease
		Ruler	98.67	-
		Vernier Caliper	99.33	-
	15	Single	94.67	Grease
		Twin	98.47	Water
		Ruler	94	-
		Vernier Caliper	99.78	-
	30	Single	94.22	Grease
		Twin	98	Grease
		Ruler	96.22	-
		Vernier Caliper	99.11	-

According to the Table 3, vernier caliper was the best tool for thickness measurement of the stainless steel plates (almost 100%) as it had performed precisely on each day of inspection compared to the UTTM and ruler. This may be due to the best calibration procedure of the digital vernier calliper have been taken carefully. Referring to the previous study, The most crucial part of calliper calibration is ensuring compliance with stated accuracy criteria [8]. Therefore, the accurate data obtained by the vernier calliper is basically influenced by the calibration steps before running the measurement where the zero error is the most crucial part need to prevent.

The differing results of the most precise method could be attributed to a variety of factors. The UTTM method was not the optimal method in this study since there was a lack of knowledge and experience in handling ultrasonic instruments. In addition, the significant reading of thickness sometime cannot be obtained because the standardization of material, range, sweep, or velocity on the instrument control changed incorrectly which leads to erroneous data interpretation. The standardization steps was crucial as mentioned in ASME Designation: E797/E797M-10, Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo (2015).

4. Conclusion

The results show that the ultrasonic testing thickness measurement (UTTM) can still measure the thickness of 1.5 mm plates. According to the results of each day of inspection, the thickness measurement changed, which could be due to inaccuracies or other factors such as the incompetent of the operator while implement UTTM method. UTTM method required a high skill operator with good skills in interpreting result. As a result, UTTM could provide results that have high accuracy and dependable if ruler and vernier calliper cannot be applied. The results show good percentage when compared with ruler and Vernier calliper with lower error.

Furthermore, the UTTM was used to investigate the thickness properties of Stainless Steel plates. Several factors influencing thickness measurement were revealed. It was demonstrated that different couplant and probe types have distinct effects on UTTM thickness measurement, as seen in the previous figure of results. The reading of data was regulated by the coupling's different qualities such as viscosity, acoustic impendence, and transmission coefficient.

Finally, different probes crystal works differently in terms of the working principle. The contradictory results between both probes demonstrate the distinction. However, for the specimens with thick of 1.5mm, the double crystal probes are most precise as it has good near-surface resolution and able to measure thin plates.

A few recommendations can be made for future analysis to address the project's weaknesses. This recommendation should be valuable for future references as well as any additional research on the connected study area. To acquire the best aging effect by blasting procedure, a long amount of exposing time, around 60 to 90 days is required since environmental elements take time to maximally interacts with the specimens. Finally, the standard procedure for the fabrication of the Stainless Steel calibration block necessarily utilized not even skip any of the fabrication steps especially the heat treatment process where this might affect the quality of the calibration block.

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