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Evaluation of the Ultrasonic Flaw Detector Inspection on Single Vee Butt Welded of Carbon Steel Plate Using Three Different Couplant

Muhammad Adam Baduhalin[1], Abdul Syahmie Azree Abdul Rani[1], Eliza M. Yusup[1*]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

*Corresponding Author

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Abstract: Carbon steel plate with single vee butt welded was inspected with an ultrasonic flaw detector (UTFD) using an angle probe. Various types of couplants have been used to study their effects on ultrasonic transmission. The acoustic impedance of the couplant affects the transmission of ultrasonic waves. As a result, welding flaws were found on the root and central area of the butt weld plate. The results also show that honey has the smallest percentage difference (234.42) in terms of size accuracy compared to water (362.89) and baby oil (370.04) in identifying and measuring defect size. However, there are other factors to be considered when performing an UTFD testing. In summary, UTFD is the only method of NDT that can detect and measure all subsurface defects in the weld area, and honey gave the best results for the couplant used.

Keywords: Non-Destructive Testing (NDT), Ultrasonic Testing Flaw Detector (UTFD), conventional method and acoustic impedance

1. Introduction

Joining metals during welding requires a focused and targeted heat input. This creates internal stresses in the workpiece and deforms the structure. In addition, residual stresses develop in the heat affected zone (HAZ) of the structure. These undesirable conditions that form are found in most welded joints and, if not carefully investigated and avoided, can lead to problems with the strength of the welded joint [1]. Welding processes can lead to defects in welded joints. Defects can be due to their size, location and nature. Once these issues are identified, corrective action should be taken to eliminate them. Errors are nothing but inaccuracies in welded joints.

Welding process, joint characteristics, approach, and welding technique all influence the occurrence of defects. Wrong approaches and techniques can lead to defects leading to premature operational failure. Most of the problems that occur in welded structures are due to poor welding techniques [2]. There are three types of defects in welds including crack-like defects (under-fusion or (LOF)), central and sidewall cracks), weld defects (under-penetration (LOP) and root cracks), and volumetric defects (porosity and slag) [3].

Based on the inspection, the weld should be approved or rejected and the weld quality should also be checked. These tests prove that good welds are defect-free [4]. Non-Destructive Testing (NDT) is very important mechanism in modern industry, especially in the design of pressure vessels and welding of irrigation pipelines. It is an extensive and diverse collection of research techniques used in manufacturing and fabrication sectors to identify defects in welded materials such as small cracks and imperfections in equipment components. After inspection, NDT does not change the shape of

**Corresponding author: elizay@uthm.edu.my*

the product. Today, NDT methods are used in a variety of small to large scale manufacturing, build-to-order inspections, and repaired work components to ensure product quality, reliability, integrity, and to control defects in weld overlay materials. are used in the industry. Furthermore, this technology reduces manufacturing costs and ensures a certain level of quality [5]. Ultrasonic Testing (UT) is primarily based on short wavelength mechanical and radio frequency (RFW) beams transmitted by a probe and detected by the same or other probes. Upon inspection, HFW penetrates the material. These HFWs move through different materials at different speeds. However, the wave velocity remains constant within a given material [6]. The included time-based oscilloscope display shows the time it takes for an ultrasonic pulse to reach a reflector (defect, bare surface, or back) as the distance traveled across the oscilloscope screen. The magnitude of the reflected pulse is proportional to the size of the flaw as seen from the transmitting probe. The relationship between defect size, distance, and reflectance is complex, and considerable skill is required to interpret the data presented on the display screen [3].

Subsurface defects that are close to the surface structure can gradually develop into a chain of large problems that can go unnoticed and if not detected in advance, can lead to accidents. Therefore, an efficient NDT approach that can detect and quantify subsurface failures is essential to ensure the safety and reliability of safety-critical structures [7].

Furthermore, the coupling condition is one of the most influencing factors on pulse wave transmission [8]. It is important to understand the effects of coupling losses that occur in ensuring contact between the probe and workpiece. Sound reflection and material resistance can affect the quality of the received data needed to describe the material [9]. Couplant with high acoustic impedance have also been shown to produce much better ultrasound transmission than regular couplant [10].

Ultimately, UT operators are forced to scan weld joints inappropriately to obtain meaningful data [11]. Therefore, choosing an appropriate coupling medium is crucial to improve the transmission of ultrasonic energy between the probe and sample. The purpose of this paper is to compare the defect characterization data obtained by the UTFD for carbon steels with various couplant to study the transmission of ultrasonic energy from the transducer to the test subject.

2. Research Design and Methodology

2.1 Materials

The carbon steel single vee butt-welded plate used in this experiment exhibits the following specifications as in Table 1 and was provided by Qrent Sdn. Bhd.

Table 1 - Specification of carbon steel plate

Data	Description
Material of Test Specimen	Carbon Steel
Serial Number	141368
Type of Weldment	Single Vee Butt Weld
Welding Process	TIG/Manual Metal Arc
Dimension (mm)	12 X 300 X 300

2.2 Couplants

There are three different couplant used and the acoustic impedance were Johnson's Baby Oil (MRayIs = 1.10), honey (MRayIs = 2.89) and water (MRayIs = 1.48) as stated by [9], which were purchased from a local store.

2.3 Methods

Initially, the surface of the butt-weld carbon steel plate was cleaned to prevent difficulty of the probe. For this research, the probe specifications used is 4 MHz and angles at 45°,60° and 70. Next, the setup of the UT's machine must be accurate to get an efficient result by adjusting the value of material velocity, thickness of the materials, and other parameters on the UT's machine according to the detail of the test specimen. In this study ultrasonic testing provide the result on sizing and characterization of defect. Fig. 1 shows the general component used for UT testing.

(a)

(b)

Fig. 1 - The main equipment used for ultrasonic testing (a) rigor RFD 60 was the equipment used for UTFD in this study; (b) probe 4MHz with 45°

2.4 Calibration Process

This process must be done thoroughly due to its effectiveness in fabricating an efficient result for the data which consist of probe index calibration, p-delay adjustment, and construction of DAC curve. Probe index calibration also known as beam path and as indication to determine the distance from the index line to the edges of the block which the total length is 100mm for IIW V1 block and 12mm IIW V2 block as referred to the ASME Section V, Article 5 as shown in Table 2.

Table 2 - Reference blocks with V1 block (upper) and DAC curve (below)

Features	Purpose Of Block	Serial Number	Calibration block
V1 block	To calibrate the probe index of the transducer	18110997	
18mm ASME block	To perform a DAC curve on equipment	18140985	

2.5 Scanning Process

After the calibration process, the scanning process is the main part of this study that needs to be looked into carefully to determine the defect in the welded area. A defect is normally characterized by observing its echo dynamic pattern as the probe is scanned in two directions; along and across the defects. There are 4 types of scanning patterns, including depth, lateral, orbital, and swivel scans.

2.6 Result Validation

The result recorded was compared to the theoretical answer scheme provided by Sonaspection, which also has the Certificate of Conformance as shown in Table 3. The accuracy of the experiment data will be calculated as per Equation 1 below:

$$\text{Percentage Difference} = \frac{\text{Experimantal-Actual}}{\text{Actual}} \text{ x } 100\% \quad (1)$$

Table 3 - The original answer scheme for the test specimen from Sonaspection

Flaw no.	Flaw type	Distance from datum(mm)	Flaw length (mm)	Depth of defect from surface (mm)
1	Slag/LOF	58	16	2
2	Crack	145	25	1.2
3	Side Wall Fusion	268	21	4.5

3. Results and Discussions

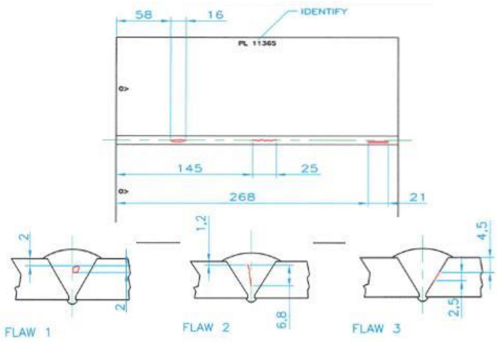
Sizing comparison of data is shown in Table 4. Obtained data of L, d and q were compared with the answer scheme of the butt welded plate. Percentage differences are summed to easily observe differences that allow couplants to better detect defect sizes. The smaller the total percentage difference, the more consistent the experimental results with the actual results. However, looking at the percentage difference between Fig. 2(b) and 2(c), there is a large gap between the obtained results and the response scheme. For example, if the crack failure depth percentage difference exceeds 100%, the percentage difference becomes large.

A couplant with high acoustic impedance has been shown to significantly improve ultrasound transmission [10]. Based on the acoustic impedance of couplant, honey has the highest acoustic impedance, followed by water and baby oil. As shown in Table 4, honey has the smallest percentage difference (234.42%). This result confirms the research by showing that couplant with high acoustic impedance and high permeability coefficient are the most effective for flaw detection [11]. Hence, honey has been proven to be excellent for defect detection due to its high acoustic impedance [12].

However, if we look at the percentage of difference in Table 5, there are significant gaps between the obtained result and the answer scheme. For example, at the percentage of difference for defect 2, depth has a big percentage of difference where it exceeds 100%.

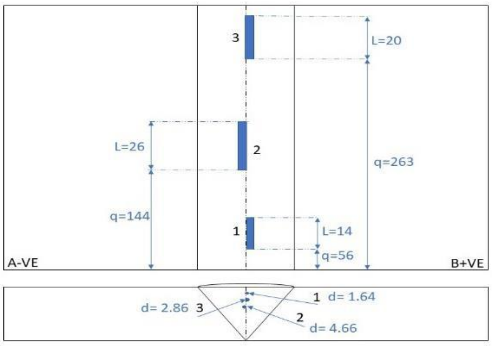
Table 4 - Butt welded plate defect diagram and sizing comparison between the answer scheme by supplier and the result

Sonagel W5 (Couplant used from answer scheme)



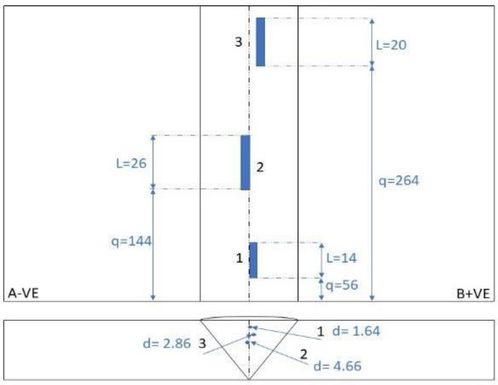
No	L	q	d
1	16	58	2
2	25	145	1.2
3	21	268	4.5

Baby oil



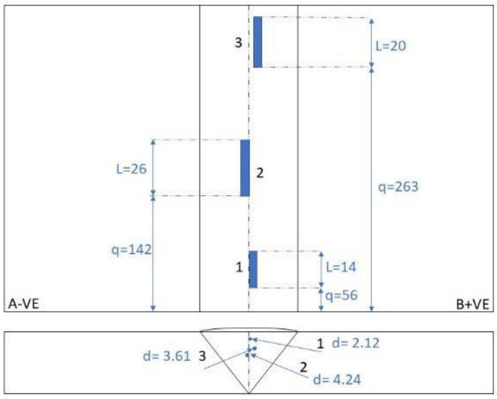
No	L	q	d
1	14	56	1.64
2	26	144	4.66
3	20	263	2.86

Water



No	L	q	d
1	14	56	1.55
2	18	144	4.37
3	20	263	2.86

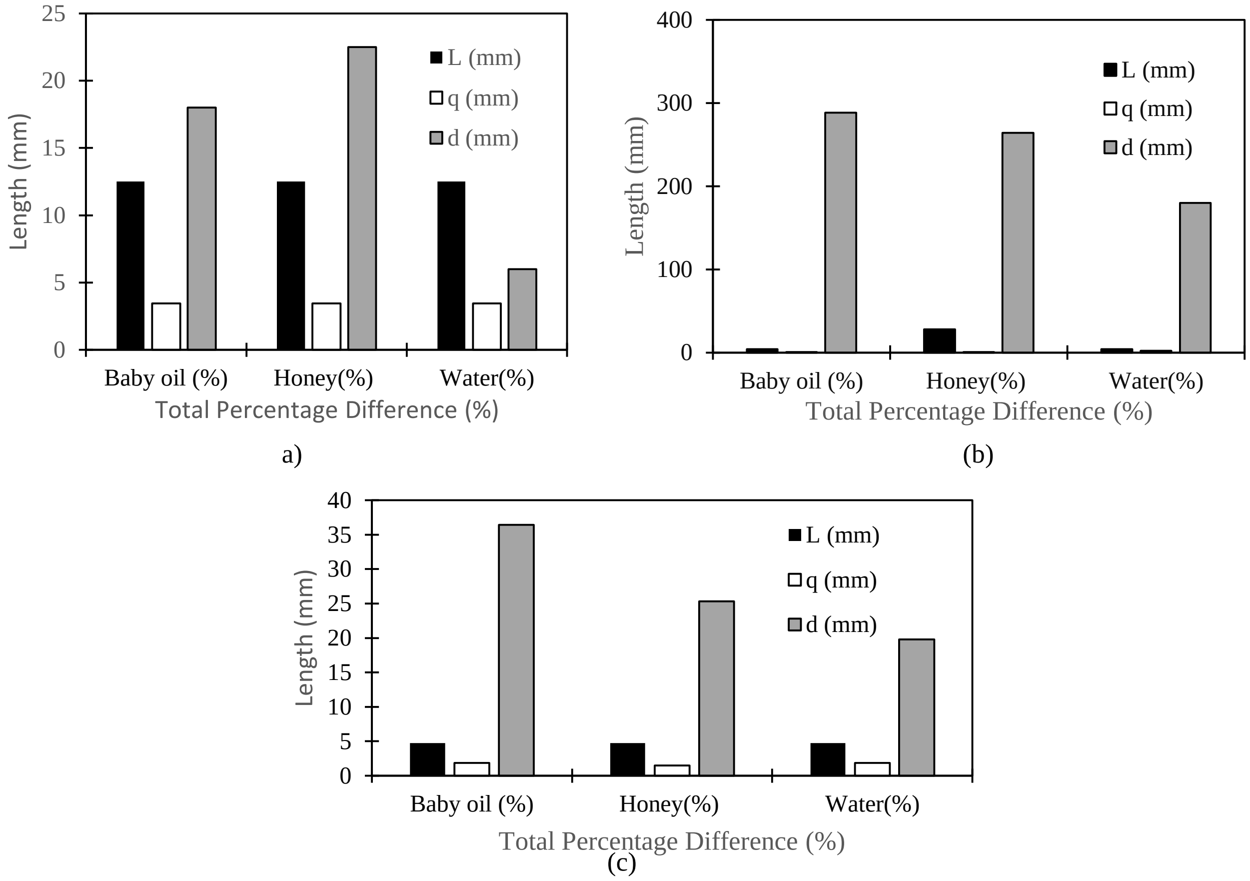
Honey



No	L	q	d
1	14	56	2.12
2	26	142	4.24
3	20	263	3.61

*Legend: L=Defect length, q=Length from datum, d=Defect depth from upper surface

A large difference in percentage sizes can be due to several factors. There are factors other than couplant that may have affected ultrasonic flaw detection, and one of them is the effect of external forces on the test probe. Experience has shown that the greater the external force on the probe, the higher the reflected echo in manual UT with the same couplant [10]. Based on our observations during the experiment, the force applied during scanning changes the reflected echo, especially when dealing with baby oil and water as couplant which could be due to their wettability.



*Legend: L=Defect’s length, q=Distance from datum, d=Defect’s depth

Fig. 2 - The comparison of defect’s characterization of using different couplants on the detection of defect (a) slag; (b) crack; (c) lack of fusion

Table 5 - The total percentage difference (%) of defect detection on Carbon Steel Plate by using different couplant by UTFD.

Indication	Couplant	L (%)	q (%)	d (%)
1	Baby oil	12.50	3.45	18.00
	Water	12.50	3.45	3.45
	Honey	12.50	22.50	6.00
2	Baby oil	4.00	0.69	288.33
	Water	28.00	0.69	264.17
	Honey	4.00	2.07	180.00
3	Baby oil	4.76	1.87	36.44
	Water	4.76	1.49	25.33
	Honey	4.76	19.87	19.78
Sum of percentage difference (%)	Baby oil		370.04	
	Water		362.89	
	Honey		234.42	

*Legend: L=Defect length, q=Length from datum, d=Defect depth from upper surface, Equally important is the wetting ability of the couplant, i.e. the ability of the liquid to maintain contact with the solid surface. It is determined by the balance of adhesive and cohesive intermolecular interactions [13]. This is related to the surface tension of the couplant and reflects the degree of molecular interaction between the couplant and the compression surface. This is often related to viscosity and the fact that a good wetting fluid can result in less air between the couplant and the two compression surfaces [10]. According to observations made during the experiment, when using baby oil and water as adhesives, more external force must be applied to the test probe than honey. This may be because honey is highly viscous compared to water and baby oil.

In addition, surface roughness also affects ultrasonic defect detection. When using the same couplant, a higher roughness surface usually produces a weaker coupling effect with lower reflected echoes. For the couplant with the lowest acoustic impedance, surface roughness has a more significant influence on the reflection amplitude [13].

4. Conclusions and Recommendations

These findings and failure analyses have been validated against failures made by the supplier. All comparisons were made to pristine defects in carbon steel butt-welded plates. The results demonstrate that UTFD can detect subsurface and internal defects in butt-welded plates. The results also show that honey is the best couplant, followed by water and baby oil, indicating that the high acoustic impedance of honey is more useful for fault detection than its low acoustic impedance.

Apart from that, honey has excellent wettability which makes the butt-welded plate easier to scan compared to the two other couplants, especially given that the rough surface of the butt-welded plate affects the scanning process. Surface roughness should also be considered when selecting a couplant. The excellent wettability and viscosity of honey made it easy to scan samples with rough and corroded surfaces.

To improve the shortcomings of the project, some recommendations can be done to improve the research and can be intended for future reference and further research on related topics. For example, to observe and compare error data, test the project again using a different kind of NDT method, such as radiography testing, where it can produce a film through the subsurface, a place that cannot be reached by the naked eye. Lastly, it is preferred to perform UTFD on other materials of the sample specifications in this study to get a variety of result comparisons among the different couplants used.

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